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THE UNIVERSITY OF ALBERTA
THE PETROLOGY OF THE SIMILKAMEEN BATHOLITH

by



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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Petrology of the Similkameen Batholith", submitted by P. Peto in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The Similkameen batholith is an eccentrically zoned Mesozoic batholith consisting marginally of older dioritic and quartz dioritic intrusives and centrally of younger granodioritic and quartz monzonitic intrusives. Selected rock samples were analyzed for silica, alumina, magnesia, titania, iron oxide, lime, strontium and rubidium by x-ray fluorescence spectrography, potash and soda by flame photometry and copper, lead and zinc by atomic absorption spectrometry. Normative magnetite, sphene, hornblende, biotite, anorthite, albite, orthoclase and quartz were computed according to the Granodiorite Norm. Simple and multiple linear regression and analysis of variance have been used in the evaluation of petrochemical data by computer analysis. The continuity of Rb abundances and the similarity of K/Rb indices between petrologic units indicates that they are comagmatic. The continuous decrease of normative hornblende, biotite, anorthite, magnetite and sphene as well as of Sr and Ca/Sr; and the continuous increase of normative albite, orthoclase and quartz as well as of Rb and Rb/Sr indicates that the Similkameen batholith evolved through a process of differentiation involving crystal fractionation of hornblende, biotite and calcic plagioclase. The Rb, Sr, Ca/Sr, and Rb/Sr distributions are clearly separable into a cumulus quartz dioritic trend and a derivative granodioritic trend. The similarity of Sr, Rb, Rb/Sr and K/Rb indices between dioritic xenoliths and their granodioritic host indicate that the xenoliths are cognate. $\text{Sr}^{87}/\text{Sr}^{86}$ abundances and high K/Rb values indicate that the Similkameen batholith is derived

from the mantle and has undergone extensive crystal fractionation involving high K/Rb bearing phases.

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CHAPTER ONE

INTRODUCTION

Introductory Statement

"A series of Mesozoic batholiths follow a northwest trend throughout British Columbia. These batholiths are of diverse size, composition, complexity and structural form, and of varying ages from Upper Triassic to Upper Jurassic. In many places they are partially concealed by younger rocks, mainly Tertiary lavas and sediments, and, unlike the Coast Range batholith, they are characterized by more subdued and mature land forms. In the main they have been little studied other than on a broad reconnaissance scale, with more detail in limited areas around significant mineral deposits. It would probably be no exaggeration to say that they are 90% or more obscured by glacial deposits."

"The Similkameen batholith with its important mineral deposits is an ideal subject for detailed study because we have a current prospecting interest and there is a good basic framework established at the Brenda copper-molybdenum deposit. The regional setting of the Brenda deposit is as yet poorly understood, and we lack details on bulk and trace element geochemistry in this essentially quartz-dioritic environment. Are we indeed looking at the very roots of a mineral deposit at Brenda?"

"I am inclined to the view that potentially greater exploration value may be derived from regional studies that are sufficiently broad, and yet include a substantial basis of solid information at and around known important mineral deposits, than to rather restrictive

case-history studies of known mineral deposits. With this in mind, it is proposed that an initial investigation be conducted into the copper potential of the Similkameen batholith, a poorly known representative of the quartz-rich Mesozoic batholiths. This, hopefully, will produce some short-term exploration benefits, and secondly, add to our broader knowledge of this type of environment. Ultimately, we may emerge with some specific criteria that can be applied to other Mesozoic batholiths." (P.E. Hirst, Exploration Geologist, Anaconda American Brass Co. Ltd., company report, 1969).

Location

The Similkameen batholith lies between the 49th and 50th Latitude and 119.75 and 120.5 degrees Longitude comprising some 900 square miles. The Similkameen batholith is bounded by Okanagan Lake to the east, by the Similkameen River to the south and the Trepanege Plateau to the north. The townsites of Princeton, Penticton and Peachland approximately define the S.W., S.E., and N.E. corners of the batholith respectively.

Physiography

The Similkameen district lies between the Coast Range to the west and the Okanagan Range to the east within the Southern Interior Plateau of British Columbia. The map area consists of broad upland areas with gently rolling summits separated by numerous creeks flowing into deeply incised valleys which constitute the master drainage systems of the region. The average elevation of the upland region is approximately 3750 feet whereas the valley floors are approximately

1200 feet above sea level. The maximum relief of the map area is 6000 feet. The major drainage valleys within the area are McNulty Creek and Hayes Creek which flow into the Similkameen River, Trout Creek and Peachland Creek which in turn flow into Okanagan Lake. The entire map area has been glaciated and covered with a mantle of overburden of variable thickness. Outcrop is generally scarce in the northern portion but becomes progressively more abundant to the south, especially on the peaks of summits. The ice movement was from the N.N.W. varying in direction only locally.

Previous Work

The Similkameen district has been documented in the past by officers of the G.S.C. such as G.M. Dawson in 1877, R.A. Daly in 1912, and C. Camsell from 1907 to 1912. During the period between 1926 and 1930 H.S. Bostock mapped the boundary of the Similkameen batholith from Princeton to Penticton on a scale of one inch to one mile. In 1960 H.M.A. Rice completed a map of the Princeton map area on a scale of one inch to four miles. It was not until 1961 when H.W. Little mapped the west half of Kettle Valley that the Similkameen batholith contact had been completely defined on a scale of one inch to four miles. In 1967 J.M. Carr mapped the Brenda Lake prospect on a scale of one inch to one mile. When Anaconda American Brass Ltd. conducted a geological reconnaissance survey in 1969 the intrabatholithic contacts were defined on a scale of one inch to two miles by the author.

Regional Geology

The Similkameen batholith is a member of an inter-batholithic

plutonic assemblage which comprises the western margin of North America. The earliest geological record of the Princeton district is represented by rocks of the Hozameen Group which consists of andesites, cherts, and limestone and on this basis has been correlated with the Cache Creek Group known to be of Permian age. This period of eugeosynclinal deposition continued into the Upper Triassic with the deposition of the Nicola Group which consists of cherts, argillites, andesites, tuffaceous and cherty argillites, tuffs and occasional lenses of limestones and quartzites. The Triassic - Jurassic boundary marks the beginning of a period of plutonism after which the Guichon batholith (200 m.y., White, et al., 1968) the Copper Mountain Stock (193 m.y., personal communication, Preto, 1969), and the Tulameen ultramafic complex (186 m.y., Leech, et al., 1963) were intruded into the Nicola Group. Rice, 1960, believed that the Similkameen batholith was intruded during this time but its relation to the Dewdney Creek Group which consists of andesites, argillites, greywackes, tuffs, sandstones and conglomerates and is thought to be of Upper Jurassic and/or Lower Cretaceous age, is uncertain. During or prior to this period of plutonism the Nicola Group was cast into a series of north trending folds. The Kingsvale Group consisting of andesites, basalts agglomerates, and greywackes and the Spences Bridge Group consisting of rhyolites, dacites, and basalts were deposited during or after uplift in a near shore environment. The Pasayten Group which is of Albian age or younger and consists of deltaic mudstones, sandstones, tuffs and agglomerates was deposited contemporaneously with the Kingsvale and Spences Bridge Groups. Its relationship to the Eagle granodiorite, which has been dated at 98 m.y. (Wanless, et al., 1967) is in

doubt. Rice, 1960, maintains that the contact is unconformable whereas Camsell and Wanless, et al, 1967, maintain the contact is a fault that became active in post Albian time. A period of further uplift in Upper Cretaceous times resulted in the deformation of the Spences Bridge and Kingsvale volcanics and was probably the result of an orogenic metamorphic episode in the Shuswap complex to the northeast.

Plutonism continued into early Tertiary times with the emplacement of the Coryell intrusions. The Coryell intrusions were followed by a period of volcanism and intermontaine deposition of the Princeton Group which consists of andesites, basalts, shales, sandstones and conglomerates thought to be Miocene in age. The most recent period of volcanism was the eruption of the Plateau and Valley basalts which intrude older plutonic rocks at several localities. Glaciation and the present state of continental erosion and peneplanation are the last remnants of the geological record in the Similkameen district.

Economic Geology

The Similkameen and adjacent country rocks contain several notable metalliferous deposits of diverse association. The Similkameen and Tulameen River gold and platinum deposits were mined for 53 years beginning in 1885. In 1897 the Nickel Plate Claim was staked thereby initiating the Hedley gold mine. The bornite - chalcopyrite deposits of Copper Mountain have been known since 1884 but it was not until 1925 when it went into production. The Brenda molybdenite - chalcopyrite mine is located at the junction of the Similkameen and Pennask batholiths. Notable coal deposits have been mined in the past in the Princeton and Tulameen Tertiary

coal basins.

CHAPTER TWO

THE PETROGRAPHY OF THE SIMILKAMEEN BATHOLITH

Introduction

The Similkameen batholith is an eccentrically zoned mosaic consisting of various calc-alkaline plutonic rocks. In the course of mapping several rock units were distinguished. Among these units are the Similkameen quartz diorite, the Isintok, Summerland and Kirton diorites, the Jura granodiorite porphyry, the McNulty Creek granodiorite and the Empress quartz monzonite. Other units such as the Valhalla granodiorite and the Coryell intrusives have been identified and correlated with units in other areas. The author has correlated the Otter intrusives (Rice, 1960) with the Coryell and has omitted them from this treatise as they have been adequately described elsewhere (Bostock, 1966).

The country rocks adjacent to the batholith at some localities have undergone thermal metamorphism producing garnetiferous gneisses, biotite schists and calcite - tremolite scarns whereas other areas show low grade alteration or none at all. Each rock unit is generally massive and relatively well preserved. Two major post secondary alteration associations were observed, chlorite-calcite veining which is usually associated with shear zones and epidote-quartz veining which is usually associated with a pink argillitized envelope contiguous with the vein. Inclusions were numerous in some rock types and virtually absent in others.

The Kirton Diorite

The Kirton diorite appears to be the earliest intrusion of the

batholith. It crops out as three major bodies in the eastern sector; the northernmost body is located to the west of Peachland south of Peachland Creek. Another body crops out along Trout Creek near the Kirton railway station and the southernmost body crops out along Shingle Creek to the west of Penticton. The Kirton is a melanocratic, fine to medium grained, hypidiomorphic granular and occasionally foliated diorite consisting of hornblende (21.6, 15)* occurring as brown subhedral medium grained phenocrysts, usually partially altered to biotite and chlorite. Biotite (6.3, 8.5) occurs as subhedral, fine to medium grained crystals some of which are pseudomorphs after hornblende or may be further altered to chlorite. Plagioclase (59.3, 9.7) occurs as subhedral, medium grained, partially sericitized phenocrysts twinned on the albite, carlsbad and pericline laws and showing continuous zoning with an average composition of An 27. Quartz (8.6, 3.4) and orthoclase (4.1, 2.2) occur as fine grained, anhedral crystals between cumulus minerals. Apatite, magnetite and sphene commonly occur as accessories.

The Isintok Diorite

The Isintok diorite crops out as three relatively small bodies the largest of which is located near Collett Creek, another body is located to the west of Hayes Creek, near the mouth of Red Creek and the third body is located near Mount Isintok. The Similkameen and McNulty Creek units have intruded the Isintok and

* (Mean, Standard Deviation), See appendix D.

inclusions of Isintok have been found in the same units.

It often displays a matted texture consisting of long slender hornblende phenocrysts which on occasion grade into a finer grained texture containing clots of feldspathic mineral. It is usually a grey or white, fine to medium grained, hypidiomorphic granular rock consisting of hornblende which occurs as subhedral, fine to medium grained, acicular crystals often twinned parallel to the length of the phenocryst. Plagioclase occurs as subhedral, fine to medium grained, continuously zoned phenocrysts having an average composition of An 45 and twinned on the albite, carlsbad and pericline laws. Biotite occurs as subhedral, fine grained phenocrysts frequently altered to chlorite. Quartz and orthoclase occur as fine grained, anhedral, interstitial crystals; accessories include apatite, magnetite, sphene and epidote.

The Summerland Diorite

The Summerland diorite crops out as two bodies in the eastern sector of the batholith; the largest body is located just north of Summerland while the other body is located north of Shingle Creek. Both bodies are intruded by and are found as inclusions in the Similkameen quartz diorites. Texturally it is a massive black and white, coarse grained, hypidiomorphic to allotriomorphic granular rock consisting of hornblende (25.4, 13.8) occurring as subhedral to anhedral, coarse grained, ophitic, commonly twinned phenocrysts. Plagioclase (57.2, 10.5) occurs as subhedral, coarse grained, tabular phenocrysts showing continuous zoning and twinned on the albite, carlsbad and pericline laws. Plagioclase phenocrysts are relatively

unaltered and have an average composition of An 48. Biotite (6.5, 7.7) occurs as anhedral, medium grained crystals usually interstitial to plagioclase. Quartz (7.4, 6) and orthoclase (3.5, 3.1) occur as anhedral, fine grained mesostasis. Common accessories include apatite, magnetite, sphene, and epidote.

The Similkameen Quartz Diorite

The Similkameen quartz diorite is an extensive unit which crops out marginally and partially encircles the Post - Similkameen intrusives. It is intrusive into the Nicola, Kirton, Isintok and Summerland units and probably has a faulted contact with the Monashee Group to the east. This unit displays a wide variety of textures which is due in part to the prominence of some particular phase in terms of habit, size and abundance relative to the other phases. Thus the relative prominence of hornblende, biotite, and plagioclase may impart various textures from porphyritic to equigranular and various compositional differences from location to location. (Carr, 1968).

The Similkameen quartz diorite is a spotty white or greyish, medium grained, hypidiomorphic granular rock consisting of hornblende (6.6, 5.6) occurring as subhedral, medium to coarse grained, ophitic and often twinned phenocrysts which are locally altered to chlorite. Plagioclase (50.5, 10.2) occurs as subhedral, medium to coarse grained phenocrysts having compositions of An 38 to An 47 in the cores and An 23 at the rims. Most crystals show complex zoning patterns ranging from patchy, oscillatory and continuous zoning as well as showing a wide variety of normal twinning on the albite, pericline and/or

carlsbad laws. Biotite (5.8, 4.9) occurs as anhedral, medium to fine grained crystals which in porphyritic varieties may occur as pseudo-hexagonal books having diameters up to one quarter on an inch. Biotite is commonly altered to a shredded or fibrous chlorite. Quartz (26.4, 7.8) and orthoclase (10.7, 6.1) occur as anhedral, fine to medium grained crystals interstitial to cumulus plagioclase, hornblende and biotite. Apatite, magnetite and sphene are distributed throughout the rock occurring mostly as inclusions within cumulus minerals.

The Jura Granodiorite Porphyry

The Jura granodiorite is an extensive unit cropping out within the interior of the batholith. It displays a sharp, chilled contact with the Similkameen and a narrow but diffuse contact with the McNulty Creek granodiorite. It generally contains numerous dark inclusions of various shapes and sizes which in places impart a gneissic character to the rock. Texturally it is a pinkish, coarse grained porphyry containing large, euhedral, microcline megacrysts set in a spotty medium grained matrix. There is a considerable range in the size, amount and composition of the matrix. Near the Similkameen contact the matrix is commonly feldspathic showing little or no mafic content and the density of megacrysts is exceptionally high but further away from the contact the matrix becomes greyish and more abundant, containing appreciable amounts of biotite and hornblende. The microcline megacrysts often occur in and/or truncate the boundaries between inclusions and their host rock. Mineralogically the Jura granodiorite consists of hornblende (4.4, 3.8) occurring as subhedral, medium to coarse grained, occasionally twinned, green phenocrysts

which may be partially altered to biotite or chlorite. Plagioclase (49, 8.2) occurs as subhedral, coarse grained phenocrysts having an average composition of An 28 and twinned on the albite and pericline laws. Plagioclase phenocrysts generally show continuous or oscillatory zoning often with resorption textures and myrmekitic rims when in contact with alkali feldspar. Biotite (5.3, 3.8) occurs as anhedral, medium to coarse grained phenocrysts commonly altered almost completely to chlorite. Quartz (26.9, 5.6) occurs as anhedral, medium to coarse grained, smoky crystals. Microcline (14.4, 6) occurs as perthitic euhedral megacrysts and as medium grained perthitic anhedral crystals which, along with quartz, constitute the matrix. Microcline megacrysts are almost invariably twinned according to the carlsbad law, show exsolution textures and contain concentrically aligned biotite and hornblende inclusions which tend to follow the periphery of the megacrysts. Accessories generally occur as aggregates wherein subhedral magnetite containing inclusions of euhedral apatite is usually rimmed by anhedral sphene.

The McNulty Creek Granodiorite

The McNulty Creek granodiorite is closely associated with the Jura granodiorite and compositionally as well as texturally there seems to be a complete gradation between them although their contact is quite abrupt. The McNulty crops out within the Jura unit along Red Creek, Grant Creek and McNulty Creek as well as occurring as a large semigradational body of McNulty and Jura along Nickel Plate Creek. Texturally the McNulty Creek granodiorite is a pink and white coarse grained, massive, allotriomorphic granular rock consisting of

biotite (4.8, 3.5) occurring as subhedral, medium grained phenocrysts usually altered to chlorite. Plagioclase (43, 8.8) occurs as anhedral, medium grained phenocrysts of composition An 13 usually showing continuous or patchy zoning and twinned on the carlsbad and/or albite laws. Microcline (24, 7.7) occurs as anhedral, medium to coarse grained, perthitic phenocrysts which commonly show cross-hatched twinning, myrmekitic rims, and the occasional carlsbad twin. Quartz (28, 5.4) occurs as anhedral, medium to coarse grained, smoky crystals. Accessories commonly occur as aggregates as in the Jura granodiorite.

The Empress Quartz Monzonite

The Empress quartz monzonite is closely related to the Jura and McNulty granodiorites; it crops out as two major bodies as well as in numerous dikes and apophyses. The largest body crops out to the south of the Thirsk dam and to the north of Shinish Creek. A small body associated with the McNulty intrudes the Similkameen along Riddle Creek. Similar bodies have been partially outlined to the southeast of Rampart Lake and to the north of Tepee Lakes. Texturally, the Empress is a buff coloured, fine to medium grained, allotrimorphic granular aplite consisting of anhedral, fine grained muscovite (2.3, 1.6) and minor biotite altering to chlorite. Plagioclase (33.6, 6.7) occurs as anhedral, medium to coarse grained crystals of composition An 12 generally lacking zoning and twinned on the albite and carlsbad laws. Quartz (30.9, 4) occurs as anhedral, medium grained crystals. Microcline (32.9, 6.1) occurs as anhedral, fine to medium grained, perthitic crystals commonly showing cross-hatched twinning and

occasionally showing carlsbad twinning. Apatite is occasionally present but aggregates of magnetite and sphene are the most abundant.

The Valhalla Granodiorite

The Valhalla granodiorite crops out as one large body directly east of Peachland. It intrudes the Similkameen and Jura units and is itself intruded by the Coryell. The Valhalla granodiorite is a leucocratic, medium grained, hypidiomorphic granular rock consisting of hornblende (1.5, 2.4) occurring as subhedral, fine grained phenocrysts. Biotite (4.8, 2.3) occurs as subhedral, fine to medium grained crystals. Plagioclase (49.9, 9.5) occurs as subhedral medium to coarse grained phenocrysts showing continuous and/or oscillatory zoning and twinned on the labite, carlsbad and pericline laws. Some phenocrysts are poikilitic and show resorption rims; the average composition is An 26. Quartz (28, 5.5) occurs as subhedral, coarse grained phenocrysts and microcline (15.8, 10.3) occurs as subhedral, medium to coarse grained, perthitic phenocrysts showing cross-hatched twinning.

The Jura Xenoliths

The ubiquitous occurrence of mafic xenoliths within the Jura suggests that they are significant constituents of that unit. In general they are dark, medium to fine grained, hypidiomorphic, equigranular or porphyritic rocks consisting of hornblende occurring as subhedral, medium grained, ophitic phenocrysts and biotite occurring as subhedral, fine grained phenocrysts which are usually altered to chlorite. Plagioclase of andesine composition occurs as subhedral, medium grained phenocrysts usually showing continuous zoning and

twinned on the albite law. Quartz and orthoclase occur as anhedral, fine grained, interstitial minerals. Common accessories are magnetite, apatite and sphene.

CHAPTER THREE

THE PETROCHEMISTRY OF THE SIMILKAMEEN BATHOLITH

Introduction

The purpose of this chapter is to document and analyse the petrochemical variation within the Similkameen batholith. The petrogenetic implications of the trends described in this chapter will be deferred to a subsequent chapter when they will be discussed in conjunction with the petrography and field observations of the previous chapter. Table 3.1 is a compilation of chemical analyses on rocks taken from the Similkameen batholith. Rock analyses beginning with GSC and HHB were obtained from G.S.C. Bulletins 115 and 126.

(Maxwell, et al., 1965; Bostock, 1966). Normative computations were based on the Granodiorite Norm which is described in appendix C.

Major Oxide Trends and Distributions

The means and standard deviations of major oxide and normative constituents of batholithic rocks are listed in Table 3.2. The major oxide trends of tables 3.1 and 3.2 are shown in figures 3.1 to 3.4. It is manifest from these that the observed trends are continuous, determinate and approximately linear. These trends as plotted against the Larsen Differentiation Index (LDI) are therefore aptly described by the regression parameters of Table 3.3. The numeric restrictions on variables of constant sum result in a large proportion of negative correlations (Chayes, 1960) which is indicated by the rise of silica, potash and soda and the sympathetic decline of alumina, magnesia, titania, iron oxide, and lime. It is also evident from

Table 3.3 that silica, iron oxide, lime and magnesia have the greatest slopes, the units of which are expressed as weight percent oxide per unit of index. It should be noted that intercepts represent the average concentration of a particular component at the differentiation index of zero and that an estimate of the composition of any rock within the series for a particular differentiation index can be computed from the regression equations implicit in Table 3.3.

The following observations are evident from Table 3.2.

1. The mean chemical abundances of the petrologic succession change in accordance with their relative ages, i.e. that units become less basic from oldest to youngest with a few minor exceptions.

2. There is a continuous compositional variation between those units and there are no apparent compositional discontinuities within the petrologic succession.

3. In general the variances of the chemical constituents within the series decrease with decreasing basicity.

4. The Isintok diorite appears to be slightly more basic but closely related to the Similkameen quartz diorite and similarly the McNulty Creek granodiorite appears to be slightly more basic but closely related to the Empress quartz monzonite.

5. The Valhalla granodiorite has a relatively narrow compositional range and is compositionally as well as temporally distinct from other units.

Generally most of the observations are evident in the Larsen variation diagrams of figures 3.1 to 3.4. The larger dispersion of the soda, titania and alumina trends is due to the conspicuous absence of these components in the Larsen index resulting in a subsequent

decline of association. The potash and soda trends of Figure 3.4 merit attention in that the slope of the potash trend shows a distinct increase at LDI equals 15 whereas the slope of the soda trend appears to be on a decline at that point.

Normative Trends and Distributions

As changes in elemental trends do not impart any knowledge concerning the mineralogical phases which determine the course of their behavior, it is more instructive to plot normative variation diagrams. Table 3.4 lists the regression parameters of normative trends computed against the LDI. These trends are continuous, approximately linear, determinate and all are significant at the 5% level with the exception of the biotite trend. Figure 3.5 is most instructive and clearly displays the normative trend which dominates the entire petrologic succession. Normative hornblende plus biotite plus anorthite were computed against the independent index of silica and a similar trend to Figure 3.5 was observed possessing a correlation coefficient of $-.96$. Multiple linear regression analysis in the latter case indicates that hornblende accounts for 51.9% of the variation of the acidity index whereas biotite and anorthite account for 34.4% and 5.7% respectively. The regression equation for the dependency of silica on these mafic phases is given by weight percent $\text{Silica} = 78.9 - .346 \text{ Hornblende} - .367 \text{ Biotite} - .409 \text{ Anorthite}$. The F - value is 204.3 and is easily significant at the 1% level. The regression analysis was based on a total of 57 degrees of freedom. Figures 3A to 3D are ternary projections of normative compositions within the normative tetrahedron Ab-Qtz-Or-An. The following observations concerning the distributions of bulk compositions within the

Granodiorite Tetrahedron are evident.

1. The distribution of bulk compositions indicate a compositional succession in accordance with the temporal succession of petrologic units.

2. There is a progressive decrease in anorthite and a concomitant increase in orthoclase and quartz in conjunction with the temporal succession.

3. There is a considerable degree of dispersion within the distribution of bulk compositions.

4. The major trend begins at approximately An 31, Ab 38, Or 12, Qtz 19 and terminates at approximately An 6, Ab 34, Or 23, Qtz 37. These observations are illustrated in figures 3.6, 3.7 and 3.8.

Minor Element Trends and Distributions

Minor elements are often very instructive and diagnostic petrogenetic parameters and consequently are discussed in detail. The Rb and Sr distributions are displayed in Figure 3.9 from which the following observations are evident.

1. Strontium is considerably more abundant than Rb in rocks of basic composition but generally becomes less abundant in rocks of more acid composition.

2. As Sr abundances decrease there is a complementary increase in Rb abundances as bulk compositions become progressively more acidic.

3. At LDI = 15 there is a distinct inflection in the slope of both the Rb and Sr trends.

4. Strontium abundances show a considerable degree of dis-

persion for indices less than 15 but are more restrained for indices greater than 15.

The Larsen Differentiation Index of 15 marks the compositional boundary between the Similkameen and Jura units, consequently the elemental distribution for LDI less than 15 is referred to as the Pre - Jura trend whereas the distribution for LDI greater than 15 is referred to as the Post - Similkameen trend. Table 3.5 lists the regression parameters of Rb and Sr distributions for both the Pre - Jura and Post - Similkameen trends. Only Post - Similkameen regression trends are significant at the 5% level. It is evident from Table 3.5 and Figure 3.9 that at the stated error level both Rb and Sr trends are contiguous. The Sr trends, however, appear to be discontinuous at LDI = 15 with the Post - Similkameen trend displaying a higher Sr abundance at that index.

An attempt was made to determine which phases control the distribution of Rb and Sr trends and multiple linear regression parameters are listed in Table 3.6. The regression for the Rb distribution is given by $Rb = 150.78 + .694 \text{ Orthoclase} - 4.28 \text{ Anorthite} - 1.05 \text{ Hornblende} - .005 \text{ Biotite}$ and the regression equation for Sr is given by $Sr = 62.23 + 28 \text{ Anorthite} + 3.8 \text{ Hornblende} + 2.07 \text{ Orthoclase} + .38 \text{ Biotite}$. Both are significant at the 1% level and it is obvious from the analysis that normative orthoclase accounts for most of the Rb distribution whereas normative anorthite accounts for most of the Sr distribution.

Copper, lead and zinc distributions computed against the LDI indicate that copper and zinc show a tendency to decrease in abundance as bulk compositions become progressively more acidic. Both

trends are significant at the 1% level and are listed in Table 3.7. Lead, however, does not have a significant trend but this may be due to a lack of analytical precision.

The K/Rb Distribution Trend

Figure 3.10 displays a correlation diagram between Rb and K; the regression parameters are listed in Table 3.7. It is evident that Rb follows K relatively closely which is further exemplified in Figure 3.11 which indicates that the Rb and K times 100 trends are congruent over the observed range of differentiation indices. It is not surprising therefore that the K/Rb index is approximately constant over the entire petrologic succession. In order to determine whether K/Rb indices among petrologic units are significantly different an analysis of variance was used. The results are listed in Table 3.9. The tabulated F - value for 8 and 41 degrees of freedom with a probability of a larger F of .05 is 2.18. This is smaller than the computed F - value, hence the Null hypothesis that there is no significant difference between the K/Rb means among petrologic units is rejected. Applying the least significant difference criterion it was found that at the 5% level the differences between two means becomes significant only for values between 50 ± 5 K/Rb units. In general this implies there is a significant difference only between the extreme ends of the composition range at the specified error level.

The Ca/Sr Distribution Trend

Figure 3.10 displays a Ca and Sr correlation diagram; the associated regression trend is listed in Table 3.7 from which it is

obvious that Sr follows Ca quite closely. Figure 3.12 is a Ca/Sr distribution diagram from which it is evident that there is a tendency for the Ca/Sr index to decrease with increasing LDI and that there is a marked discontinuity in the trend at $LDI = 15$. The regression and population parameters of the Pre - Jura and Post - Similkameen Ca/Sr trends are listed in Table 3.8. Figure 3.13 clearly indicates that Sr is enriched relative to Ca in the Post - Similkameen trend and depleted relative to Ca in the Pre - Jura trend.

The Rb/Sr Distribution Trend

Figure 3.14 displays the Rb/Sr distribution from which the following observations are evident.

1. The distribution shows an exponential increase of Rb/Sr as bulk compositions become progressively more acidic.
2. That the trend is almost symmetrical about intermediate Rb/Sr compositions.

TABLE 3.1

Partial Chemical Analyses of Rocks from the Similkameen Batholith

ID NUMBER	2426	GSC156	HHB1	2157	HHB2	2565	2659	2534	2017
ROCK UNIT	K	K	K	K	K	K	I	I	XI
SiO ₂	49.54	51.08	52.30	55.93	61.00	62.77	95.24	59.40	63.12
Al ₂ O ₃	18.67	19.77	17.70	18.34	16.20	17.91	18.07	17.29	19.09
TiO ₂	1.21	0.45	1.20	0.79	0.70	0.62	1.15	0.84	0.77
Fe ₂ O ₃	10.25	3.60	8.50	7.77	6.06	6.25	7.60	7.67	4.67
MgO	3.53	4.57	3.20	3.46	2.60	0.74	3.10	3.09	1.44
CaO	7.82	16.30	7.10	6.56	4.80	6.07	6.42	6.05	3.81
Na ₂ O	3.48	2.56	4.00	3.14	3.80	4.04	4.20	3.51	4.93
K ₂ O	2.07	0.28	2.80	1.65	2.80	1.18	1.68	2.22	1.65
Rb	38	--	--	66	--	36	62	82	47
Sr	825	--	--	496	--	542	579	545	332
Cu	28	--	--	35	--	6	32	15	--
Pb	25	--	--	10	--	15	10	15	--
Zn	17	--	--	48	--	20	42	48	--
TOTAL	96.57	98.34	96.80	97.67	97.96	99.59	101.4	100.1	99.48

TABLE 3.1 (continued)

Granodiorite Norms

Magnetite	04.7	0	03.5	02.2	02.0	06.6	02.7	02.8	03.1
Sphene	01.3	0	01.5	0.5	0.6	01.2	01.4	01.0	01.3
Hornblende	40.3	58.0	52.1	27.9	22.5	15.4	50.1	50.6	22.4
Biotite	13.1	0	0	25.4	20.5	0	0	0	05.1
Anorthite	15.2	29.7	10.3	15.1	11.5	21.6	08.4	07.9	09.3
Albite	18.7	09.8	21.9	17.2	23.0	30.1	23.0	19.2	35.3
Orthoclase	05.0	0	10.7	00.9	07.6	06.0	06.1	08.4	07.0
Quartz	01.6	02.4	00.1	10.8	12.4	19.0	08.2	10.1	16.6
Larsen DI	-3.0	-6.9	01.4	02.5	09.7	09.0	04.3	05.2	12.8
Plag. An	43.4	74.0	30.6	45.3	32.0	40.3	25.5	28.1	19.8

NOTE: Major oxides and minor elements are expressed as wt. % and ppm respectively.

TABLE 3.1 (continued)

ID NUMBER	2369	2047	1962B	2498	2286	GSC113	2624	2029	1983A
ROCK UNIT	I	SD	SD	SD	SD	S	S	S	S
SiO ₂	65.51	45.09	49.22	50.95	55.65	58.36	58.72	58.94	59.06
Al ₂ O ₃	16.91	16.81	13.94	14.15	19.29	18.38	17.24	18.19	18.04
TiO ₂	0.49	1.49	1.16	1.31	0.96	0.54	0.82	0.62	0.64
Fe ₂ O ₃	4.02	16.69	11.80	9.76	11.41	10.83	4.68	5.91	5.84
MgO	0.77	5.31	5.68	9.21	2.72	2.60	3.46	2.35	2.35
CaO	3.33	9.40	9.51	9.70	4.63	7.20	6.05	5.54	5.58
Na ₂ O	4.60	2.21	2.19	2.43	2.43	3.15	3.75	3.51	3.18
K ₂ O	3.00	0.78	2.32	1.04	0.85	1.98	1.95	1.75	2.58
Rb	94	17	71	34	118	--	64	40	59
Sr	395	531	467	367	346	--	384	465	488
Cu	18	110	10	50	35	--	630	12	25
Pb	10	25	10	20	10	--	10	25	10
Zn	42	96	65	23	42	--	35	55	42
TOTAL	98.63	97.78	95.82	98.55	97.94	103	96.67	96.81	97.27

TABLE 3.1 (continued)

Granodiorite Norms

Magnetite	03.5	06.9	02.3	0	07.9	06.9	9	02.5	02.3
Sphene	0.7	01.2	0.8	0.5	01.3	0.5	0.8	0.7	0.6
Hornblende	0	47.3	74.0	92.6	49.0	42.9	56.2	43.1	21.2
Biotite	15.8	20.0	0	0	0	0	0	0	19.3
Anorthite	13.8	13.9	07.9	0	04.4	14.5	06.6	10.5	15.6
Albite	35.1	09.0	07.9	05.7	14.2	17.4	20.2	21.9	20.0
Orthoclase	12.7	0	06.5	01.2	03.1	07.6	07.1	07.5	07.4
Quartz	18.5	01.8	0.7	0.1	19.9	10.1	09.0	13.8	13.7
Larsen DI	16.7	-15.6	-08.3	-10.6	0.6	0.8	07.3	07.6	08.5
Plag. An	27.0	59.4	48.6	0	22.6	44.0	23.5	31.0	42.3

TABLE 3.1 (continued)

ID NUMBER	2364	HHB3	2527	GSC97	2342	2644	2611	1942A	GSC72
ROCK UNIT	S	S	S	S	S	S	S	S	S
SiO ₂	60.11	61.40	61.34	62.08	63.06	63.14	64.45	64.54	66.55
Al ₂ O ₃	17.41	18.80	17.13	17.19	17.90	17.01	18.42	17.50	16.21
TiO ₂	0.70	0.50	0.64	0.54	0.53	0.56	0.53	0.54	0.40
Fe ₂ O ₃	6.12	5.01	5.58	4.16	4.04	4.87	7.05	3.88	3.78
MgO	1.98	1.10	2.35	1.17	1.53	1.61	1.61	1.62	1.32
CaO	4.82	5.90	5.85	4.54	4.21	5.27	4.82	4.27	3.86
Na ₂ O	4.15	5.00	3.52	5.12	3.98	3.26	3.52	4.32	4.07
K ₂ O	2.47	0.80	2.04	2.96	2.72	2.00	2.13	2.47	2.84
Rb	72	--	63	168	55	71	55	--	--
Sr	359	--	451	--	997	407	454	--	--
Cu	8	--	26	--	22	10	10	32	--
Pb	10	--	20	--	15	20	15	10	--
Zn	32	--	58	--	45	32	29	32	--
TOTAL	97.76	99.51	98.45	98.48	97.97	97.72	102.5	99.13	99.03

Granodiorite Norms

Magnetite	03.4	04.0	02.0	02.8	01.9	02.9	05.3	01.8	02.0
Sphene	0.8	0.8	0.8	0.8	0.6	0.8	0.8	0.8	0.4
Hornblende	18.4	22.0	42.0	11.7	15.2	22.1	30.4	26.3	13.1
Biotite	16.7	0	0	10.6	13.8	07.8	0	03.4	11.9
Anorthite	13.5	18.8	11.3	15.4	13.2	15.7	11.2	10.5	12.5
Albite	27.2	35.5	21.4	36.7	28.0	22.4	23.1	29.8	28.8
Orthoclase	07.8	08.8	08.6	12.6	10.5	07.9	09.7	11.1	11.5
Quartz	12.3	10.1	13.9	09.4	16.9	20.4	19.4	16.4	19.7
Larsen DI	09.6	10.3	08.7	13.8	13.9	11.3	10.1	14.2	16.0
Plag. An	31.9	33.3	33.3	28.4	30.8	39.8	31.4	25.0	29.1

TABLE 3.1 (continued)

ID NUMBER	HHB4	1986	2687	2824	2633	2050A	2488	2642	2201
ROCK UNIT	S	J	J	J	J	M	M	M	M
SiO ₂	68.70	65.18	65.89	66.59	67.27	70.85	69.83	72.49	72.90
Al ₂ O ₃	16.60	16.26	15.96	17.60	16.71	14.98	14.63	15.25	16.80
TiO ₂	0.20	0.59	0.61	0.42	0.52	0.36	0.39	0.29	0.33
Fe ₂ O ₃	1.79	4.32	4.23	4.42	3.45	2.32	2.52	1.60	0.20
MgO	0.70	1.58	1.53	0.77	1.61	1.68	0.77	0.39	0.39
CaO	3.00	3.63	3.67	1.83	3.25	2.01	2.16	1.28	0.54
Na ₂ O	4.60	2.90	3.69	4.16	3.96	4.12	3.28	3.86	3.55
K ₂ O	3.10	2.90	3.46	3.02	2.38	3.62	4.11	3.96	3.59
Rb	--	101	83	111	112	124	153	185	152
Sr	--	547	604	417	465	256	350	208	94
Cu	--	25	25	12	10	15	25	10	12
Pb	--	5	10	15	15	30	10	20	10
Zn	--	38	38	26	32	20	45	38	17
TOTAL	98.69	97.36	99.04	98.81	99.15	99.87	97.69	99.12	98.30 ²⁹

Grandiorite Norms

Magnetite	0.9	02.2	02.2	04.4	0.9	0	01.5	01.4	0
Sphene	0.2	0.8	0.9	0.8	0.5	0.2	0.5	0.6	0.6
Hornblende	07.6	15.8	20.9	08.5	09.0	15.6	0	08.9	0
Biotite	06.8	14.3	07.4	07.7	21.2	14.1	16.1	0	09.0
Anorthite	11.7	10.6	09.1	05.5	10.5	04.2	09.0	03.0	01.8
Albite	35.8	20.3	25.4	32.9	27.5	28.3	25.5	31.7	30.6
Orthoclase	15.4	11.4	15.2	15.1	07.1	14.5	19.0	22.8	19.7
Quartz	21.6	24.7	18.8	25.2	23.3	23.2	28.3	31.3	38.3
Larsen DI	20.5	15.1	16.0	18.2	16.5	21.3	21.9	24.8	26.7
Plag. An	23.5	32.8	25.2	13.7	26.5	12.2	25.1	08.9	05.2

TABLE 3.1 (continued)

ID NUMBER	2434	2706	2463	2368	1983B	2256	2664	2436	2820
ROCK UNIT	M	M	M	M	E	E	E	E	E
SiO ₂	72.90	73.47	73.88	75.66	70.85	71.26	74.78	74.24	78.23
Al ₂ O ₃	14.54	14.32	13.94	14.41	13.58	14.46	13.88	14.92	12.56
TiO ₂	0.31	0.40	0.32	0.21	0.27	0.35	0.17	0.33	0.19
Fe ₂ O ₃	2.30	1.95	2.01	1.16	1.34	1.75	0.92	0.21	0.95
MgO	0.39	0.39	0.39	0.37	0.37	0.39	0.37	0.37	0.20
CaO	2.16	1.61	2.04	0.65	1.14	1.30	1.16	0.43	0.62
Na ₂ O	3.52	3.44	3.79	3.57	5.72	4.24	3.22	4.34	3.46
K ₂ O	3.56	4.05	2.52	4.07	5.24	4.67	4.57	4.85	4.30
Rb	114	140	--	171	203	120	98	138	185
Sr	318	252	343	43	179	254	167	96	42
Cu	20	10	10	20	8	35	8	15	22
Pb	10	15	20	25	5	10	10	35	10
Zn	29	29	29	26	14	42	23	14	11
TOTAL	99.68	99.63	98.89	100.1	98.51	98.42	99.08	99.69	100.5

Granodiorite Norms

Magnetite	02.2	01.7	01.8	0.7	0.9	01.5	0.4	0	0.8
Sphene	0.5	0.7	0.6	0.3	0.4	0.6	0.2	0.6	0.3
Hornblende	0	0	0	0	0	0	0	0	0
Biotite	08.4	08.5	08.5	08.2	07.8	08.5	08.1	08.1	04.4
Anorthite	09.4	06.5	08.9	02.6	04.6	05.2	05.2	01.1	02.5
Albite	28.3	27.9	30.9	29.4	44.9	34.4	26.4	35.4	28.6
Orthoclase	18.3	21.6	12.6	21.7	27.1	24.7	24.5	26.0	23.9
Quartz	32.9	33.7	36.7	37.1	14.2	25.1	35.1	28.7	39.5
Larsen DI	23.0	24.6	22.7	27.1	26.0	25.0	27.0	28.6	28.6
Plag. An	23.8	18.1	21.4	07.8	08.8	12.5	15.7	03.0	07.5

TABLE 3.1 (continued)

ID NUMBER	2279	2397	2401	2504	2520	2203	2308	2139B	2269C
ROCK UNIT	V	V	V	V	V	XJ	X	XJ	X
SiO ₂	72.16	70.47	69.11	72.04	69.78	54.05	43.08	55.27	48.52
Al ₂ O ₃	15.75	15.18	15.36	14.46	15.15	19.20	19.58	18.95	18.32
TiO ₂	0.37	0.31	0.37	0.27	0.36	0.96	1.19	1.00	1.15
Fe ₂ O ₃	2.33	2.65	2.86	1.57	2.36	8.32	12.33	6.80	9.69
MgO	0.77	0.77	1.53	0.39	0.77	3.88	5.98	2.83	4.93
CaO	2.77	2.30	2.53	1.92	2.60	5.18	10.46	4.76	8.06
Na ₂ O	2.62	4.10	3.96	3.97	2.66	5.10	2.37	5.75	4.33
K ₂ O	2.60	2.97	3.40	3.57	2.97	1.96	1.01	1.50	2.62
Rb	95	70	72	101	87	117	12	119	187
Sr	364	409	419	504	438	449	680	352	589
Cu	20	10	12	10	12	--	--	--	50
Pb	10	10	10	15	15	--	--	--	25
Zn	32	35	42	42	35	--	--	--	96
TOTAL	99.3	98.75	99.12	98.20	96.65	98.65	96.72	96.83	97.62

Granodiorite Norms

Magnetite	01.3	01.7	0.2	01.2	01.4	01.6	01.4	02.1	01.1
Sphene	0.5	0.3	0.1	0.4	0.4	0.4	0	0.9	0.3
Hornblende	0	0	0	0	0	16.4	11.0	13.7	17.7
Biotite	16.3	16.0	28.7	08.5	16.6	40.1	53.0	32.5	42.0
Anorthite	12.0	09.9	10.0	08.5	11.5	11.9	21.6	12.4	16.6
Albite	20.6	31.6	27.5	32.4	21.2	27.1	08.7	34.7	18.8
Orthoclase	10.9	12.6	10.5	18.6	13.1	0	0	0	0
Quartz	38.5	27.9	23.0	30.3	35.7	02.3	04.2	03.5	03.4
Larsen DI	20.8	20.7	19.5	23.7	20.5	02.6	-13.1	05.5	-3.9
Plag. An	35.6	22.7	25.6	19.9	33.7	29.3	70.0	25.2	45.4

TABLE 3.1 (continued)

ID NUMBER	2303	2017B	2268
ROCK UNIT	XS	XS	XJ
SiO ₂	52.07	66.50	51.50
Al ₂ O ₃	17.80	17.50	19.91
TiO ₂	0.88	0.59	1.07
Fe ₂ O ₃	9.50	4.32	7.25
MgO	4.23	1.44	4.23
CaO	6.84	4.03	7.60
Na ₂ O	5.10	1.73	4.05
K ₂ O	1.96	1.47	2.74
Rb	39	20	87
Sr	265	291	1058
Cu	--	--	--
Pb	--	--	--
Zn	--	--	--
TOTAL	98.38	97.58	98.35

Granodiorite Norms

Magnetite	02.6	02.7	0.1
Sphene	0.6	01.0	0.5
Hornblende	43.1	30.3	20.6
Biotite	14.0	0	38.8
Anorthite	09.8	09.5	17.8
Albite	24.8	12.1	20.5
Orthoclase	03.4	07.4	01.5
Quartz	01.7	36.9	0
Larsen DI	-1.2	13.8	0.8
Plag. An	27.1	42.6	45.0

NOTE: The method of analysis for chemical constituents is given in appendices A and B. The method of construction of the Granodiorite Norm is given in appendix C.

TABLE 3.2

Mean and Standard Deviations of Chemical and Normative Constituents from Rocks of the Similkameen Batholith

ROCK UNITS	Kirton			Isintok			Summerland			Similkameen		
	Mean	Std. Dev.		Mean	Std. Dev.		Mean	Std. Dev.		Mean	Std. Dev.	
SiO ₂	55.4	5.4		61.8	9.3		50.2	4.4		62.1	3.1	
Al ₂ O ₃	18.1	1.2		17.6	1.0		16.0	2.5		17.6	0.7	
TiO ₂	0.8	0.3		0.8	0.3		1.2	0.2		0.5	0.1	
Fe ₂ O ₃	7.1	2.3		6.0	1.9		12.4	3.0		5.2	2.1	
MgO	3.0	1.3		2.1	1.2		5.7	2.7		1.8	0.7	
CaO	8.1	4.0		4.9	1.5		8.3	2.4		5.1	1.1	
Na ₂ O	3.5	0.6		4.3	0.6		2.3	0.1		3.9	0.6	
K ₂ O	1.8	1.0		2.1	0.6		1.2	0.7		2.3	0.4	
Rb	52	14		71	21		60	45		70	35	
Sr	639	232		462	118		427	87		511	232	
Cu	36.3	22.3		20.7	17.8		36.1	30.4		20.7	53.4	
Pb	19.4	8.1		15.6	9.4		18.3	7.9		14.4	7.0	
Zn	56.5	25.3		45.2	13.0		58.1	20.6		40.0	10.7	

TABLE 3.2 (continued)

Granodiorite Norms

Magnetite	3.1	2.3	3.0	0.4	4.3	3.7	2.6	1.8
Sphene	0.8	0.6	1.1	0.3	0.9	0.4	0.7	0.2
Hornblende	36.0	16.9	30.8	24.4	65.7	21.7	26.6	14.4
Biotite	9.8	11.4	5.2	7.4	0	0	8.6	6.5
Anorthite	17.2	7.2	9.9	2.7	6.5	5.9	12.9	3.0
Albite	20.1	6.7	28.1	8.3	9.2	3.6	26.3	6.4
Orthoclase	5.0	4.0	8.5	2.9	2.7	2.8	9.5	2.4
Quartz	7.7	7.5	13.3	4.9	5.6	9.5	14.7	4.3
Larsen DI	2.1	6.5	9.7	6.0	-8.4	7.7	10.9	4.7

NOTE: Major oxides and minor elements are expressed as wt. % and ppm respectively.

TABLE 3.2 (continued)

ROCK UNITS	Jura		McNulty		Empress		Valhalla	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
SiO ₂	67.1	2.2	73.0	1.7	73.9	3.0	70.7	1.3
Al ₂ O ₃	16.6	0.7	14.8	0.9	13.9	0.9	15.0	0.3
TiO ₂	0.5	0.1	0.3	0	0.2	0.1	0.3	0
Fe ₂ O ₃	3.7	0.9	1.7	0.8	1.0	0.6	2.3	0.5
MgO	1.4	0.4	0.4	0.1	0.3	0.1	0.8	0.4
CaO	2.9	0.9	1.5	0.7	1.0	0.6	2.4	0.3
Na ₂ O	3.8	0.5	3.6	0.2	5.4	1.7	3.5	0.7
K ₂ O	3.1	0.5	3.7	0.6	4.7	0.3	3.1	0.4
Rb	101	17.6	152	24.6	149	44	77	22.8
Sr	487	138	210	122	147	81	510	183
Cu	18.8	24.2	11.9	6.7	12.3	5.4	16.3	11.6
Pb	12.9	4.7	12.6	4.1	12.3	6.9	12.3	3.1
Zn	30.8	7.8	30.4	8.9	17.0	11.3	37.2	4.5

TABLE 3.2 (continued)

Granodiorite Norms

Magnetite	1.9	1.6	1.3	0.7	0.7	0.6	1.1	0.6
Sphene	0.6	0.3	0.5	0.1	0.4	0.2	0.3	0.1
Hornblende	13.6	5.1	0	0	0	0	0	0
Biotite	12.9	5.7	8.4	4.6	7.4	1.7	17.2	7.2
Anorthite	8.0	2.9	5.9	3.3	3.7	1.8	11.4	3.1
Albite	26.9	4.6	29.2	2.1	34.0	7.2	26.7	5.6
Orthoclase	12.7	3.5	19.3	3.3	25.2	1.3	13.1	3.2
Quartz	23.0	2.5	34.0	3.6	28.5	9.7	31.1	6.2
Larsen DI	17.4	2.4	24.4	2.0	26.9	1.5	21.0	1.6

TABLE 3.3

Simple Linear Regression Analysis of Major Oxide Trends

OXIDE	SiO ₂	Al ₂ O ₃	MgO	TiO ₂	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O
SLOPE	.74	-.10	-.14	-.02	-.29	-.24	.02	.08
INTERCEPT	54.16	17.19	3.75	.93	8.61	7.39	3.42	1.72
CORRELATION COEFFICIENT	.98	-.62	-.91	-.89	-.93	-.92	.29	.81
COEFFICIENT OF DETERMINATION	95	39	83	80	86	85	8	67
STANDARD ERROR OF ESTIMATE	1.83	1.42	.74	.14	1.28	1.12	.86	.62

NOTE: Major oxides are regressed upon LDI.

TABLE 3.4

Simple Linear Regression Analysis of Normative Trends

PHASE	BIO	HBL	AN	AB	QTZ	OR	HBL+BIO+AN	QTZ+OR
SLOPE	-.23	-1.48	-.24	.53	.91	.57	-1.96	1.49
INTERCEPT	14.24	38.71	13.50	18.67	7.28	3.91	66.42	11.20
CORRELATION COEFFICIENT	-.22	-.78	-.51	.74	.86	.88	-.97	.93
COEFFICIENT OF DETERMINATION	5	61	26	55	74	77	93	86
STANDARD ERROR OF ESTIMATE	11.8	13.4	4.75	5.57	6.13	3.56	5.77	6.69

TABLE 3.5

Simple Linear Regression Analysis of Rb and Sr Trends

	PRE - JURA		POST - SIMILKAMEEN	
	STRONTIUM	RUBIDIUM	STRONTIUM	RUBIDIUM
SLOPE	-3.51 ⁺ ₋ 3.92	1.24 ⁺ ₋ 1.30	-35.9 ⁺ ₋ 3.17	7.19 ⁺ ₋ 0.8
INTERCEPT	544	54	1123	-33
CORRELATION COEFFICIENT	-0.14	.33	-0.91	.60
COEFFICIENT OF DETERMINATION	1.9	11	83	36
STANDARD ERROR OF ESTIMATE	212.8	30	73	43
TREND VALUE AT LDI = 15	491 ⁺ ₋ 107	72.7 ⁺ ₋ 23	584 ⁺ ₋ 56	74.8 ⁺ ₋ 22

NOTE: Trend value computed at 5% level for 53 df.

TABLE 3.6

Multiple Linear Regression Analysis of Rb and Sr Trends

NORMATIVE PHASE	STRONTIUM				RUBIDIUM			
	OR	AN	BIO	HBL	OR	AN	BIO	HBL
PHASE COEFFICIENT	2.07	28.0	0.38	3.8	0.69	-4.3	-.007	-1.05
% OF VARIATION ACCOUNTED FOR	0.07	42.4	0.1	8.3	36.3	3.1	.005	6.49
INTERCEPT	62.23				150.78			
F - VALUE	12.67				10.44			
COEFFICIENT OF DETERMINATION	50.70				46.02			

TABLE 3.7

Simple Linear Regression Analysis of Minor Element Trends

CORRELATION PAIR	Cu-LDI	Zn-LDI	Rb-K	Sr-Ca	Ca/Sr-LDI
SLOPE	-0.43	-0.52	74.86	69.85	-2.13
INTERCEPT	25.08	42.02	9.69	219.7	98.88
CORRELATION COEFFICIENT	-0.43	-0.42	0.70	0.58	-0.67
COEFFICIENT OF DETERMINATION	19	18	49	34	45
STANDARD ERROR OF ESTIMATE	9.22	11.43	34.25	179.46	27.06

TABLE 3.8

Simple Linear Regression Analysis of Ca/Sr Trends

	PRE - JURA	POST - SIMILKAMEEN
SLOPE	$-2.33^{+1.27}_{-1.27}$	-0.56^{+15}_{-15}
INTERCEPT	101	56.04
CORRELATION COEFFICIENT	-0.55	-0.29
COEFFICIENT OF DETERMINATION	30	8
STANDARD ERROR OF ESTIMATE	29.89	7.63
TREND VALUE AT LDI = 15	$66^{+22.3}_{-22.3}$	$47.6^{+4.05}_{-4.05}$
MEAN	92.35	49.18
STANDARD DEVIATION	35.10	19.16

NOTE: Trend value computed at 5% level for 53 df.

TABLE 3.9

One - Way Analysis of Variance of K/Rb Distributions

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SQUARE	F - VALUE					
AMONG UNITS	8	38100	4762	2.839					
WITHIN UNITS	41	68779	1677						
TOTAL	49								
PETROLOGIC UNITS	S	V	K	J	I	E	SD	M	XJ
K/RB MEANS	171.5	154.4	146.2	128.6	125	122	120.7	102	77.6

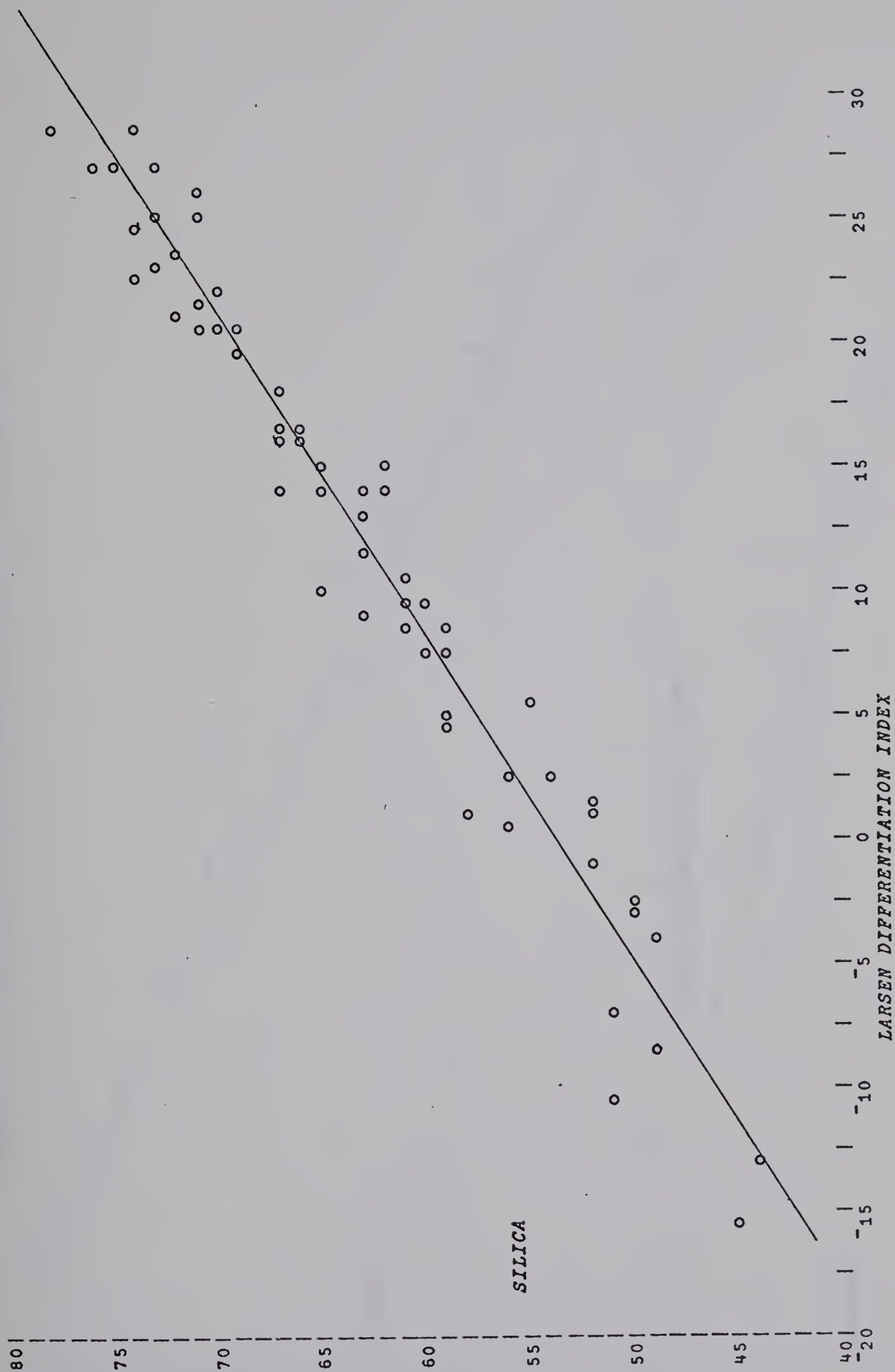
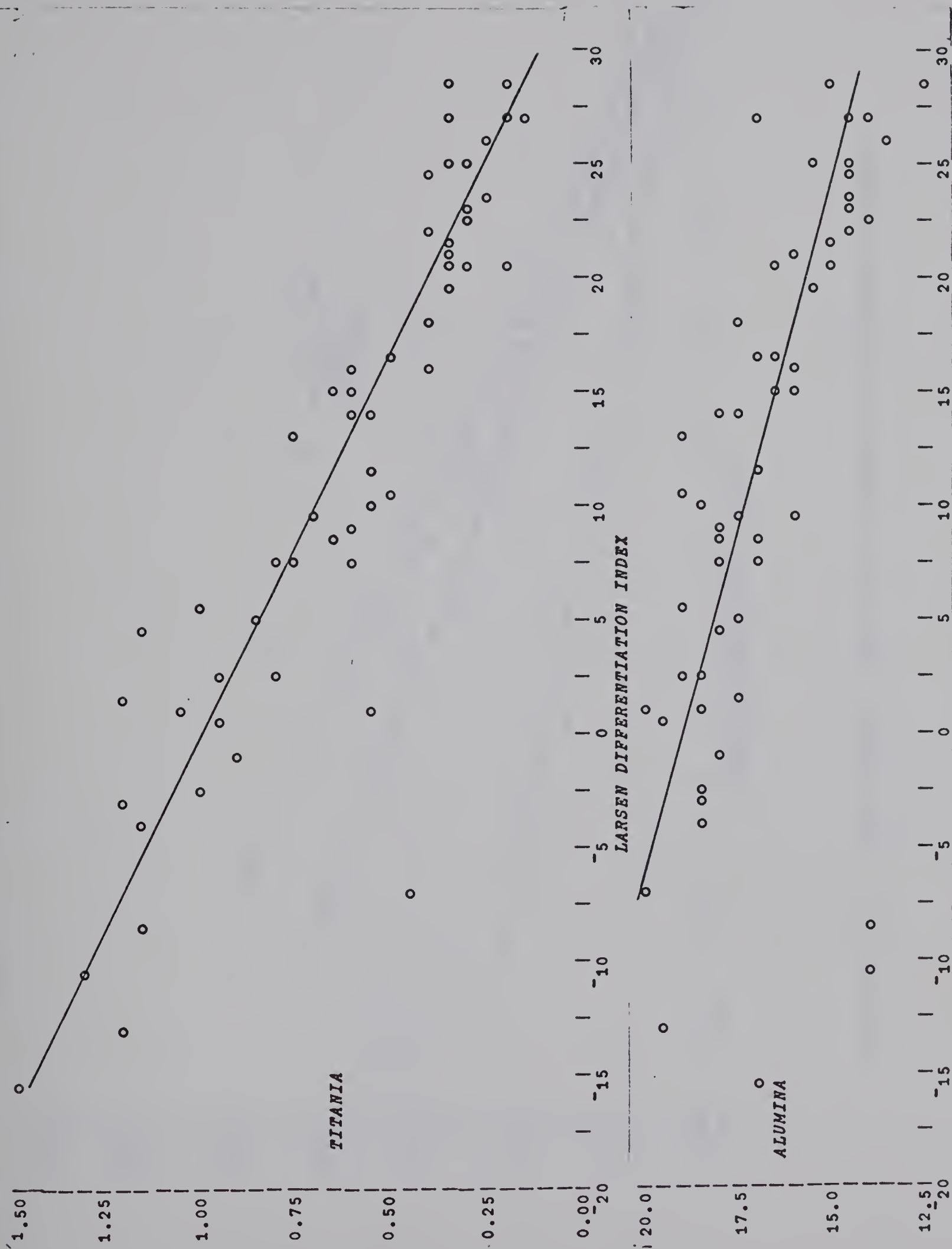


FIGURE 3.1. SILICA VARIATION DIAGRAM

FIGURE 3.2 TITANIA AND ALUMINA VARIATION DIAGRAMS



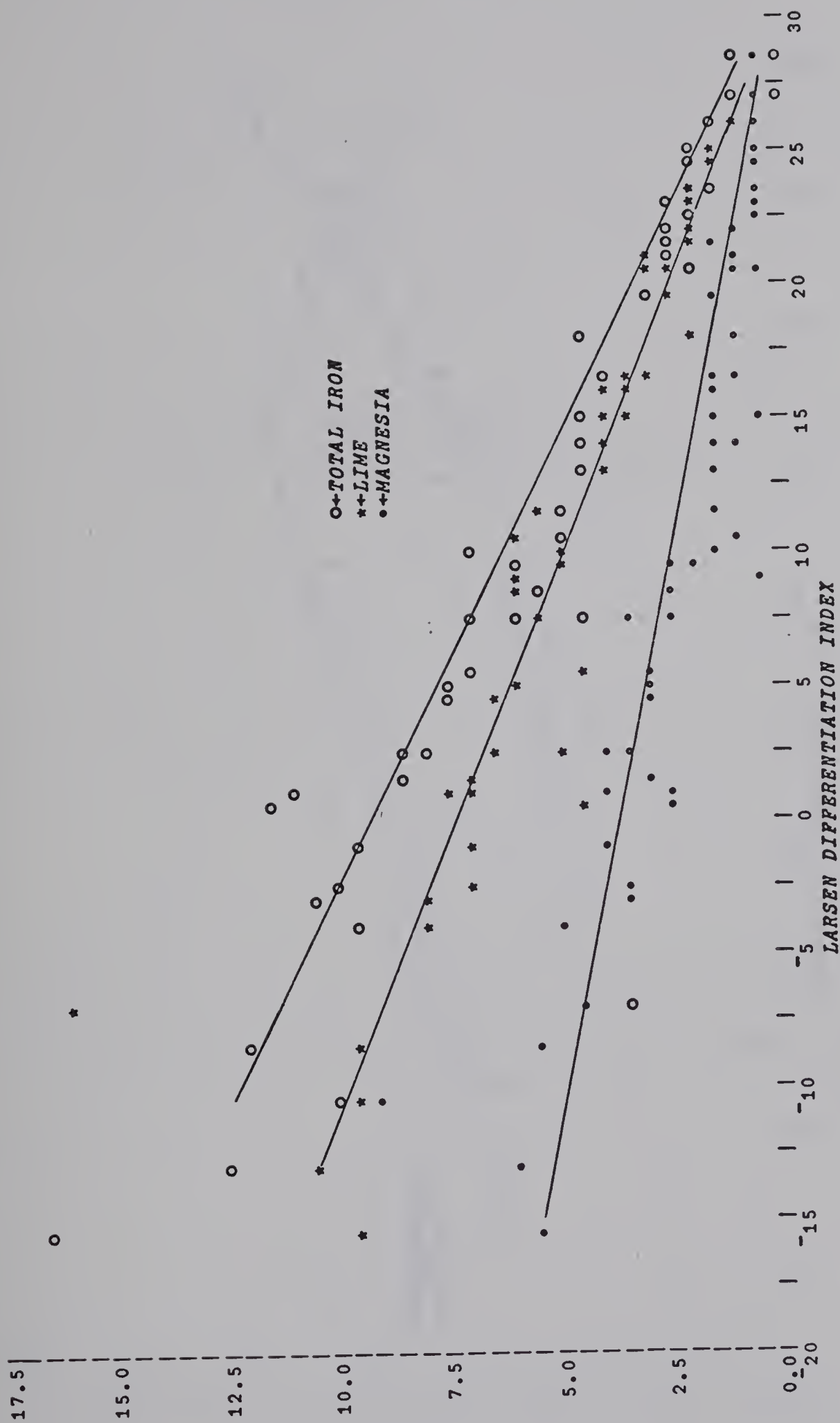


FIGURE 3.3. IRON OXIDE, LIME AND MAGNESIA VARIATION DIAGRAM

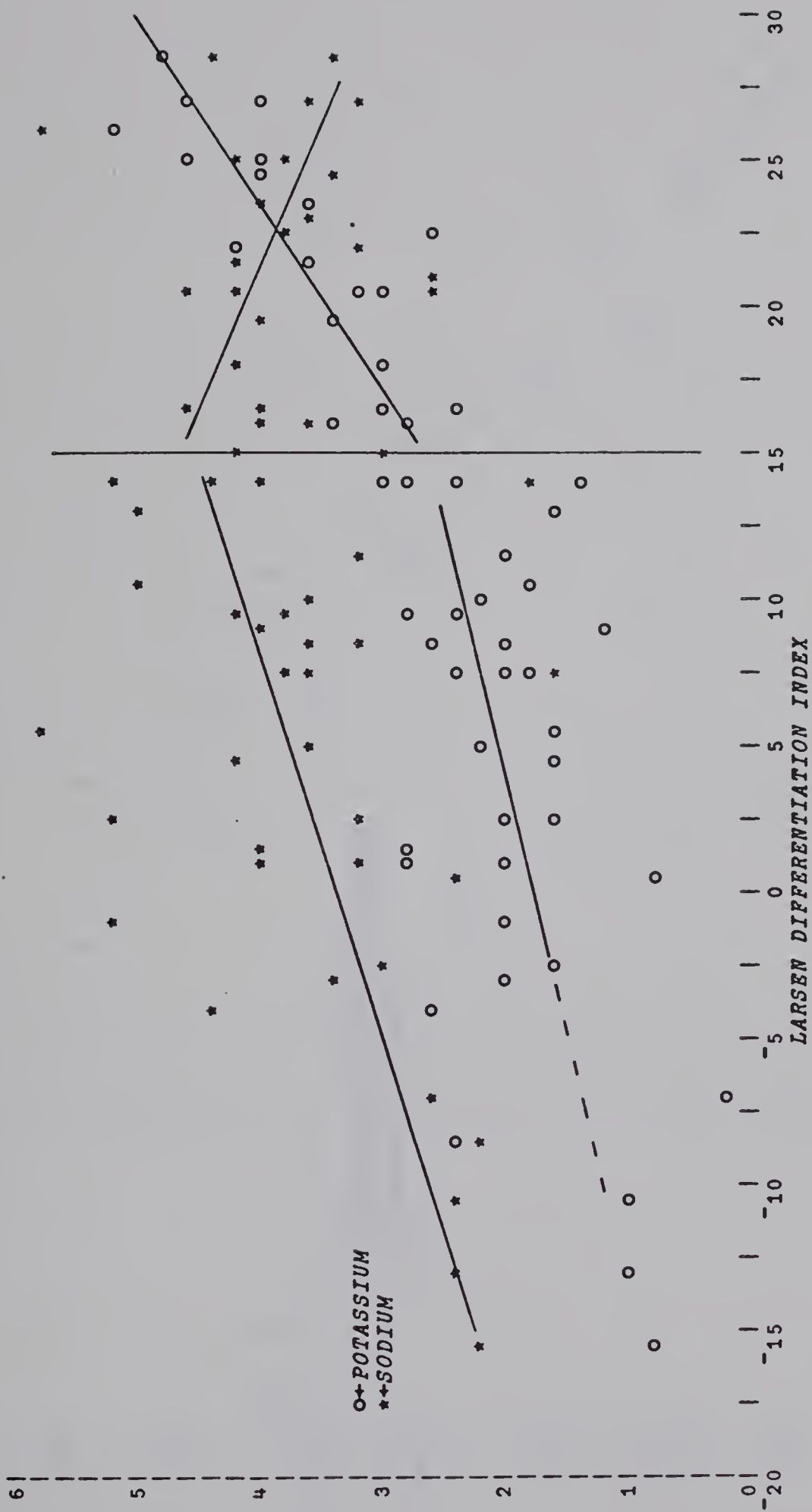


FIGURE 3.4. POTASH AND SODA VARIATION DIAGRAM

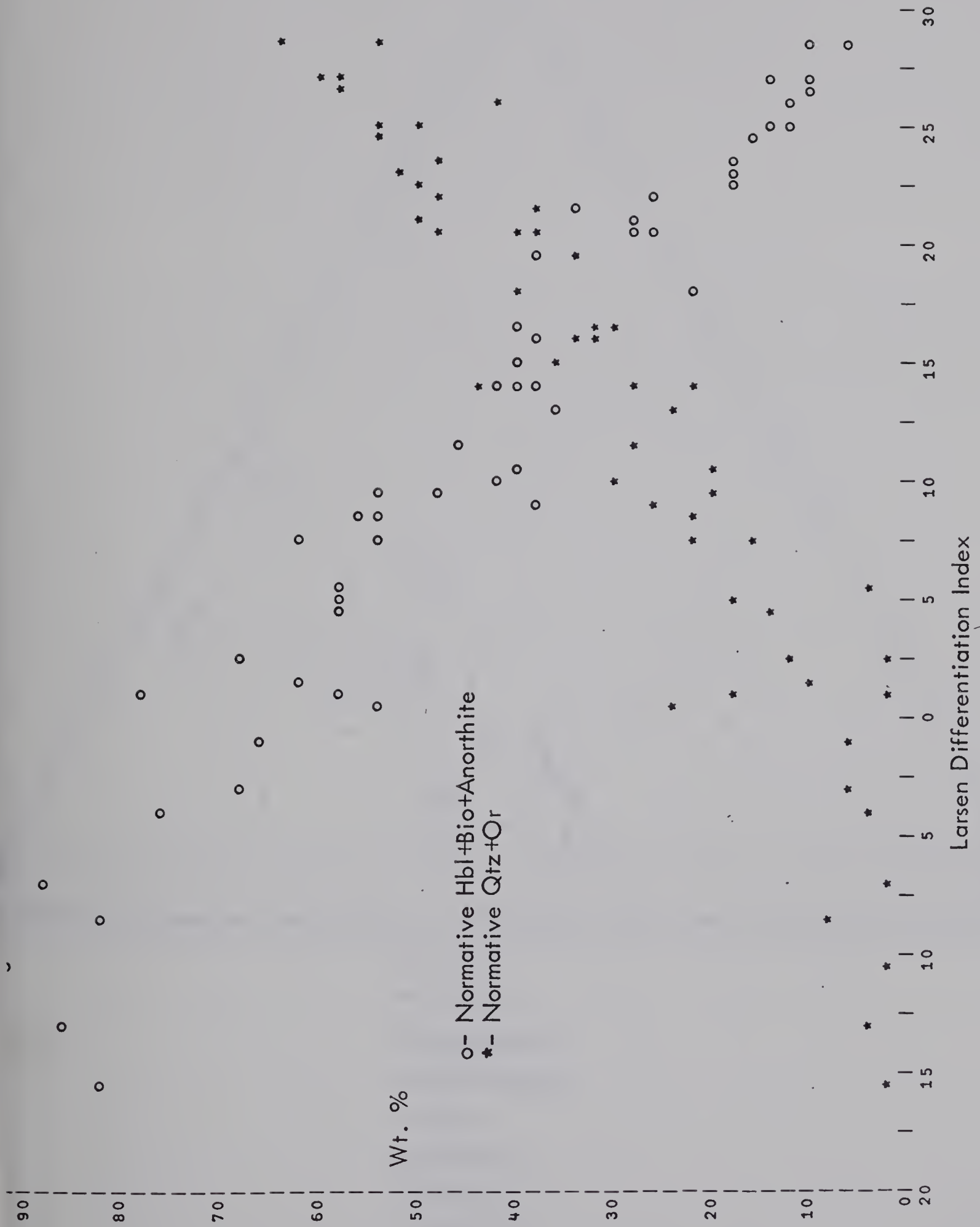


FIGURE 3.5. NORMATIVE WHOLE ROCK TREND

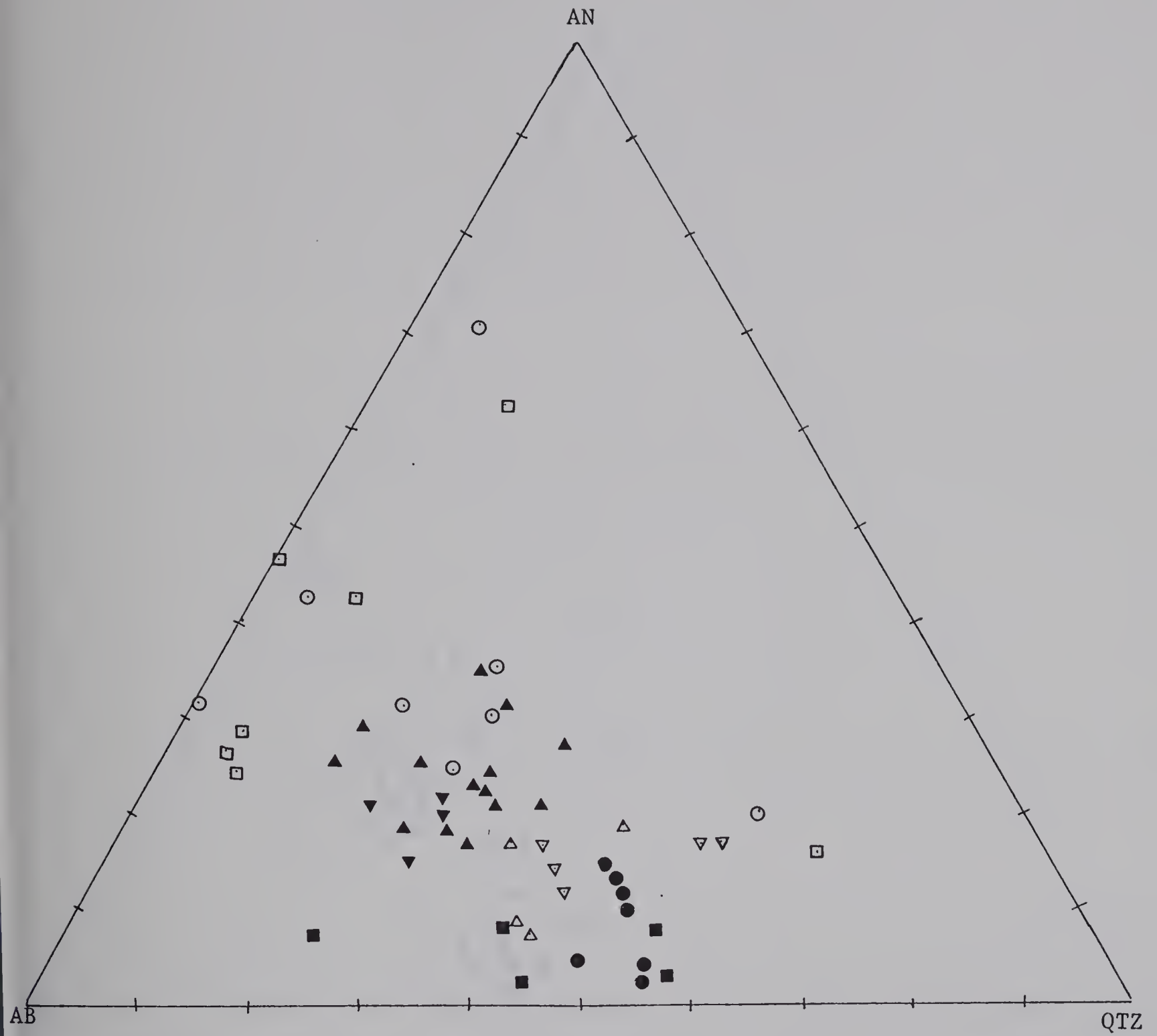


FIGURE 3A. Normative Projection of Batholithic Rocks into the System AN-AB-QTZ

- Kirton
- ▼ Isintok
- ▲ Summerland
- ▲ Similkameen
- △ Jura
- McNulty
- Empress
- ▽ Valhalla
- Xenoliths

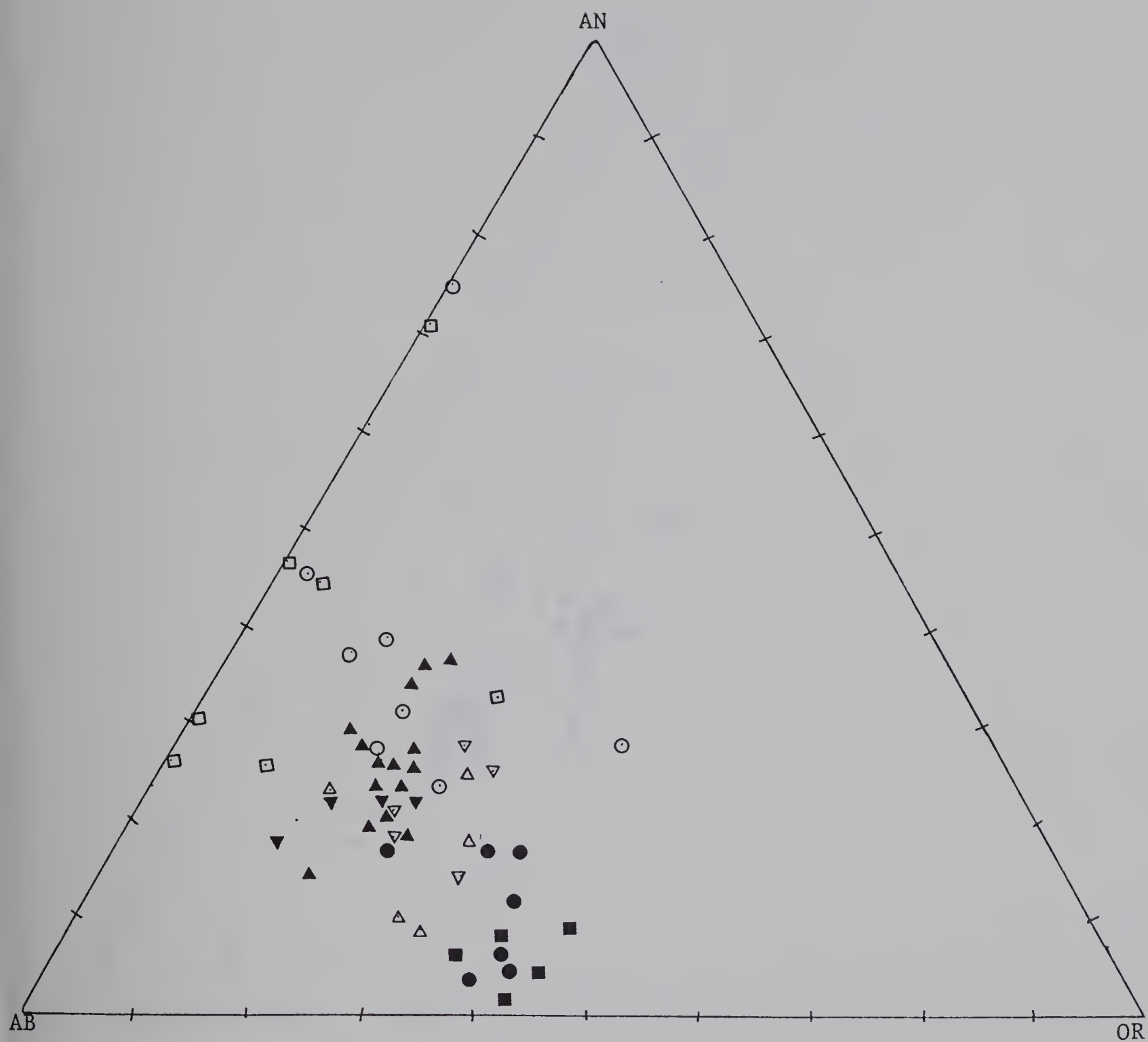


FIGURE 3B. Normative Projection of Batholithic Rocks into the System AN-AB-OR

- Kirton
- ▼ Isintok
- ▲ Summerland
- ▲ Similkameen
- △ Jura
- McNulty
- Empress
- ▽ Valhalla
- Xenoliths

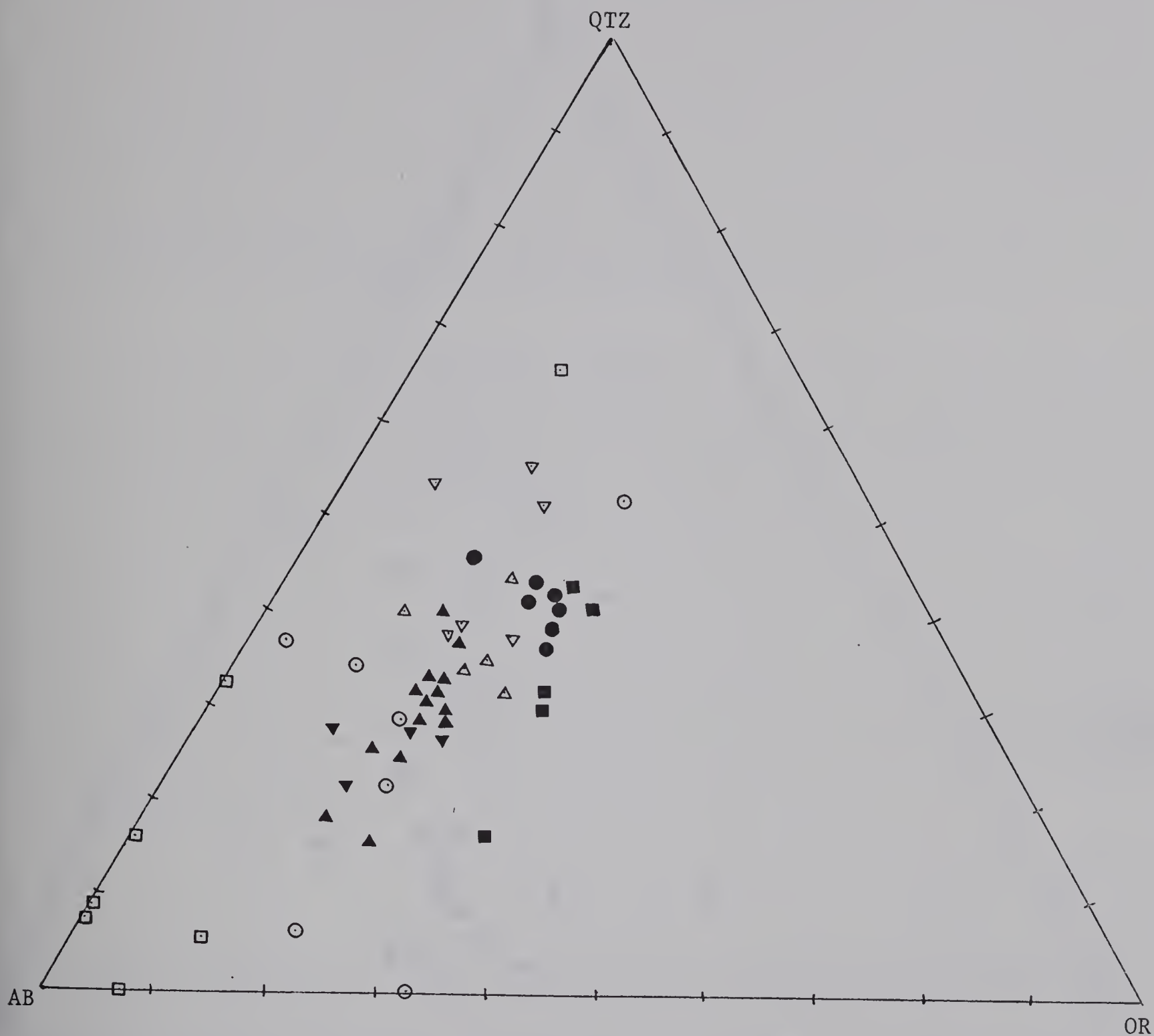


FIGURE 3C. Normative Projection of Batholithic Rocks into the System AB-QTZ-OR

○ Kirton

▼ Isintok

▲ Summerland

▲ Similkameen

△ Jura

● McNulty

■ Empress

▽ Valhalla

□ Xenoliths

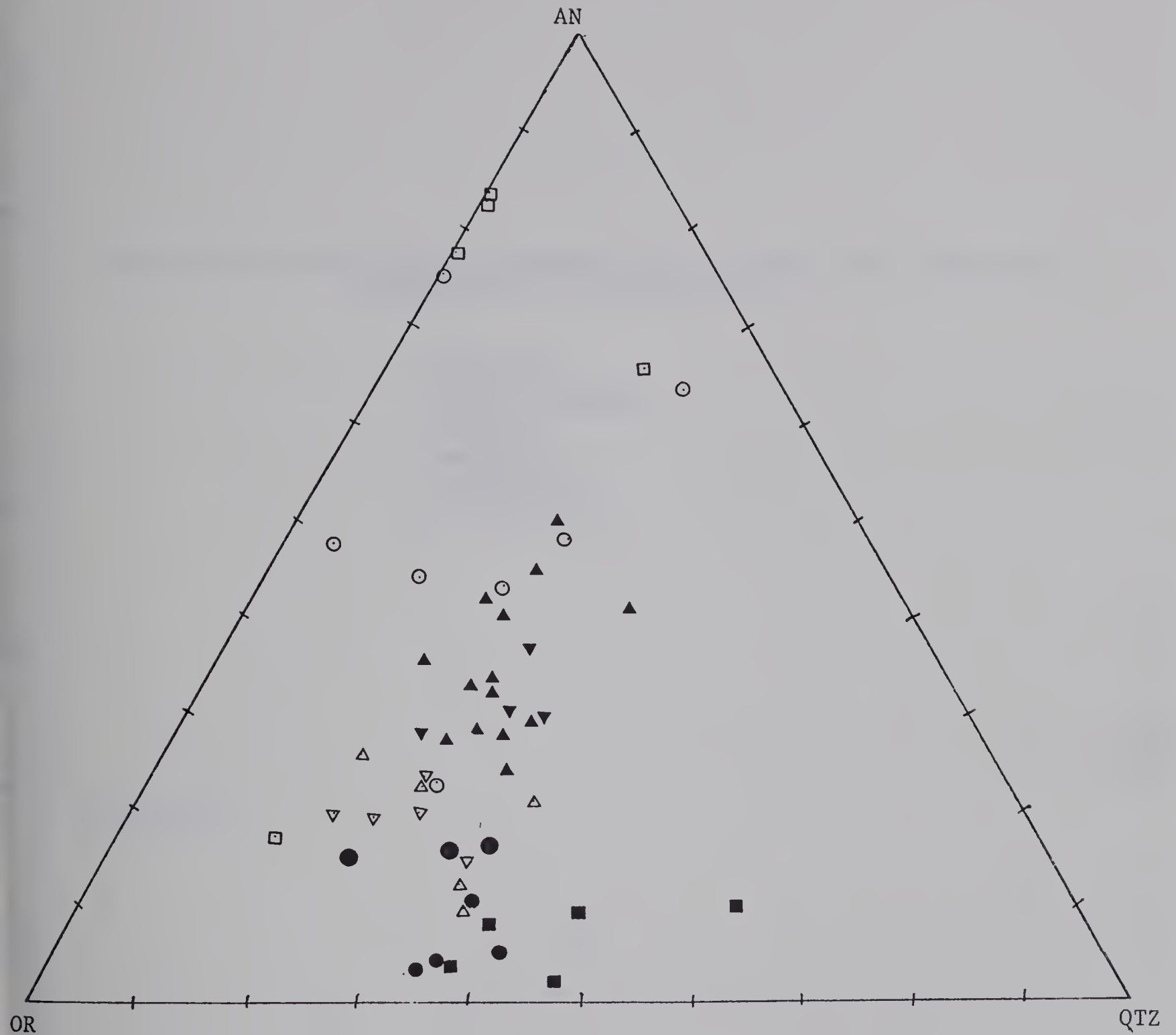


FIGURE 3D. Normative Projection of Batholithic Rocks into the System OR-AN-QTZ

- Kirton
- ▼ Isintok
- ▲ Summerland
- ▲ Similkameen
- △ Jura
- McNulty
- Empress
- ▽ Valhalla
- Xenoliths

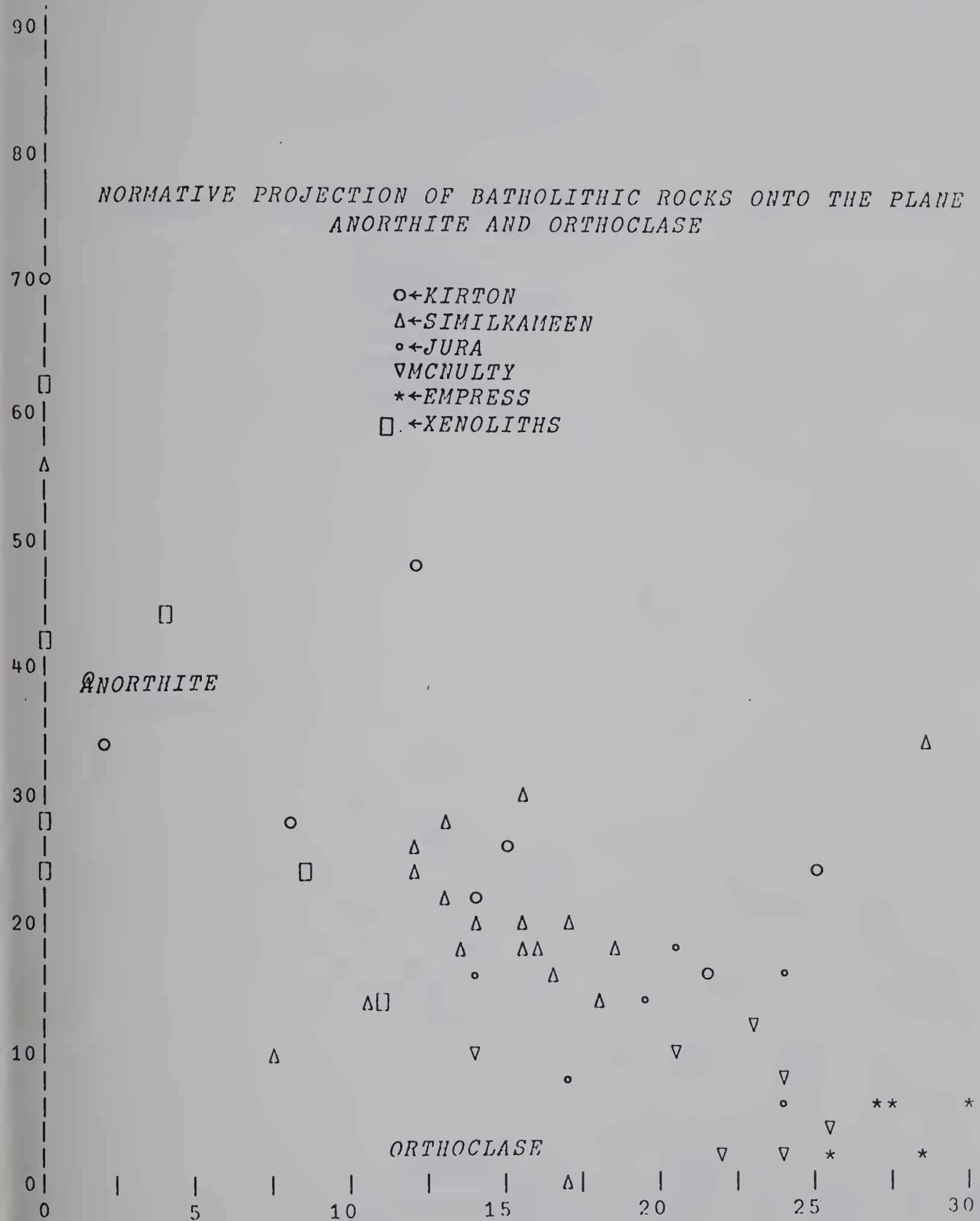


FIGURE 3.6.

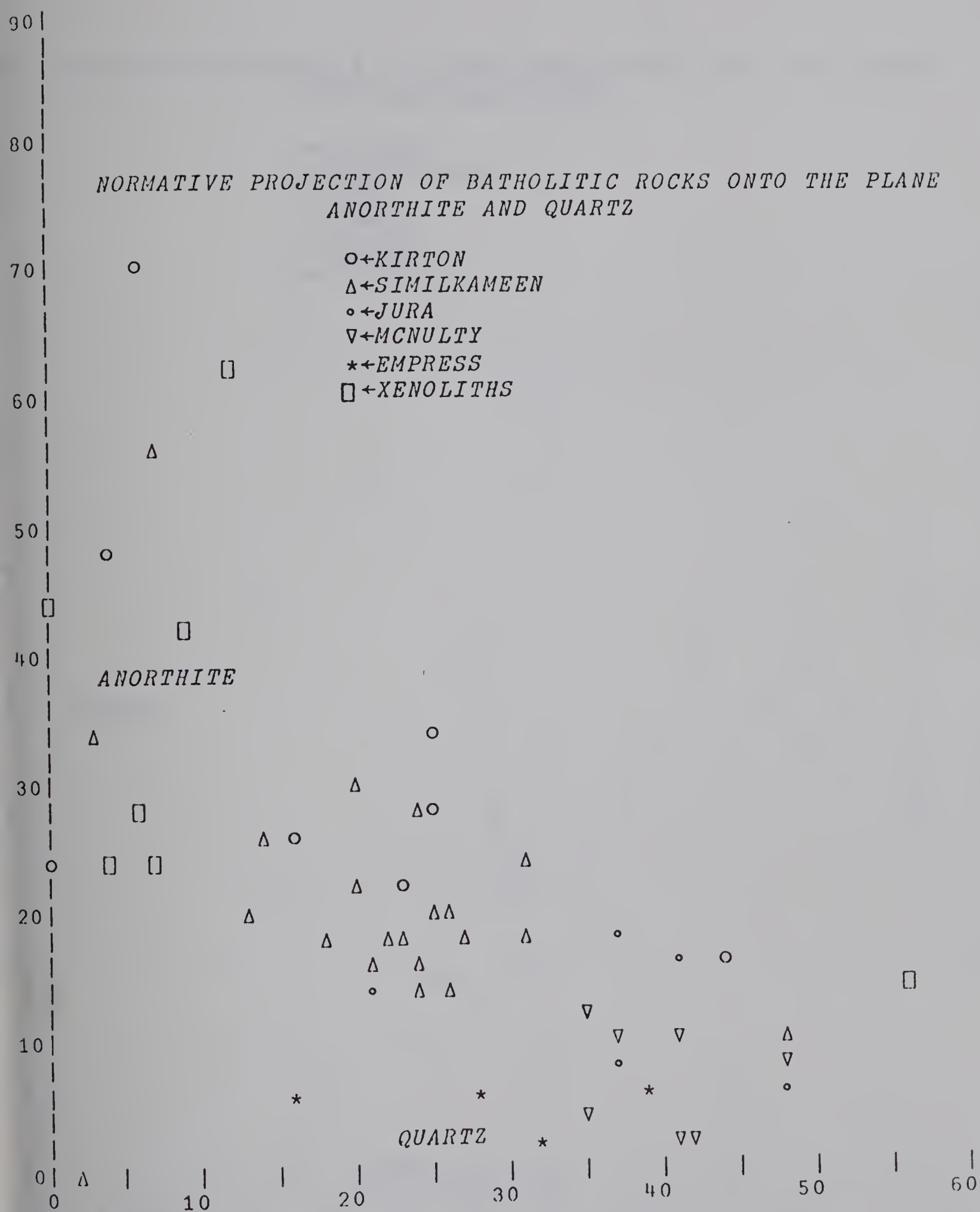


FIGURE 3.7.

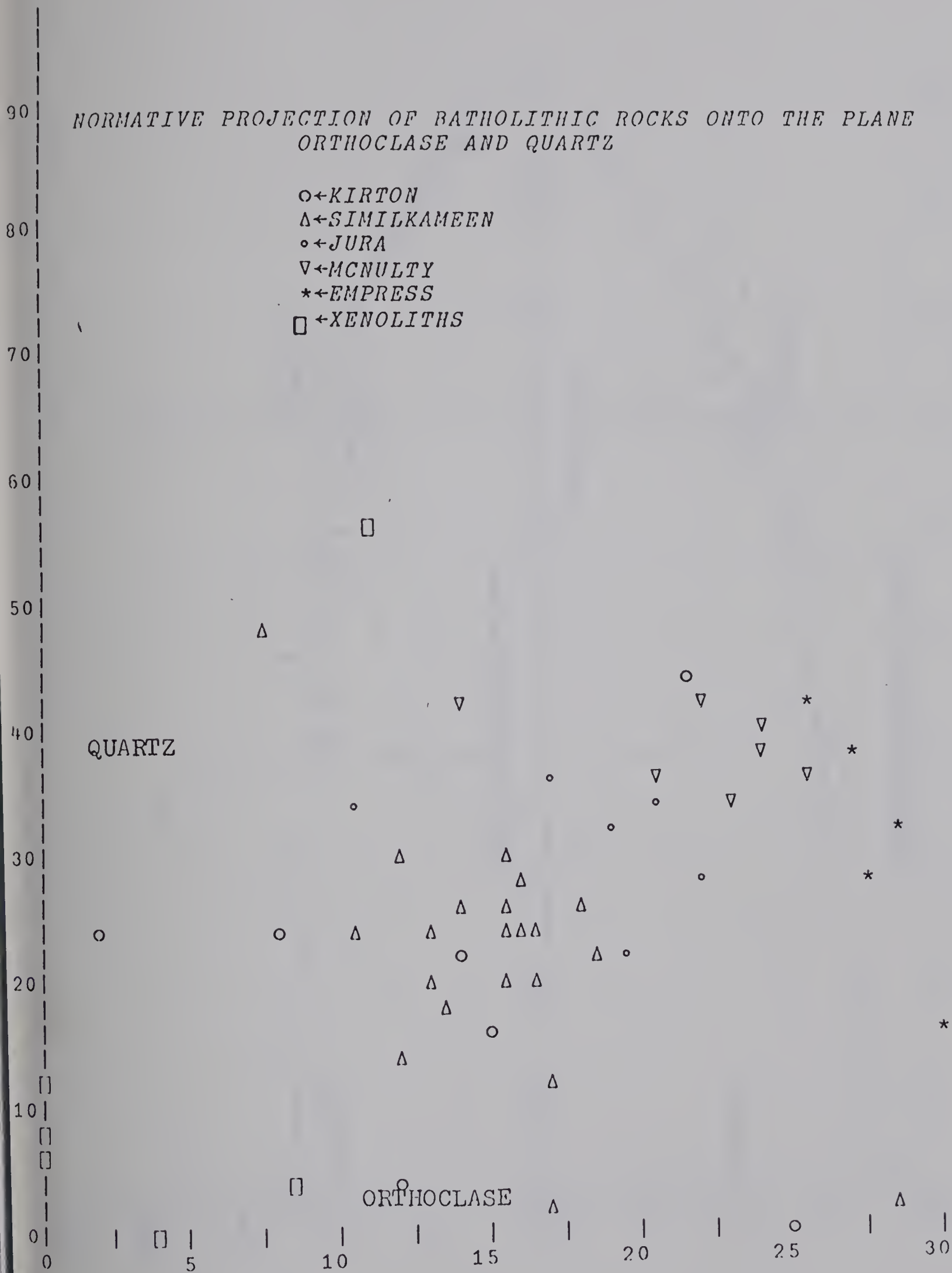


FIGURE 3.8.

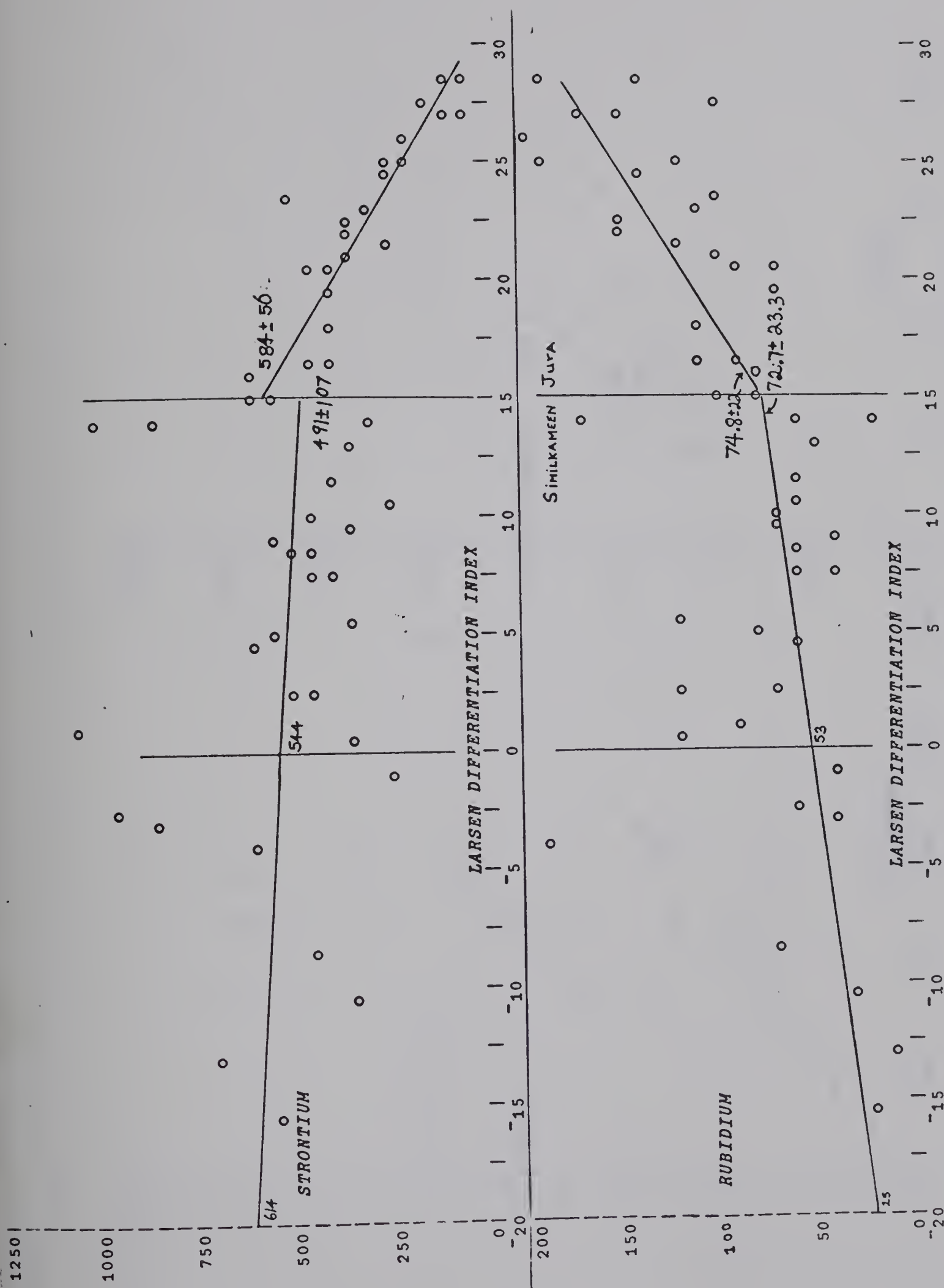


FIGURE 3.9. STRONTIUM AND RUBIDIUM VARIATION DIAGRAM

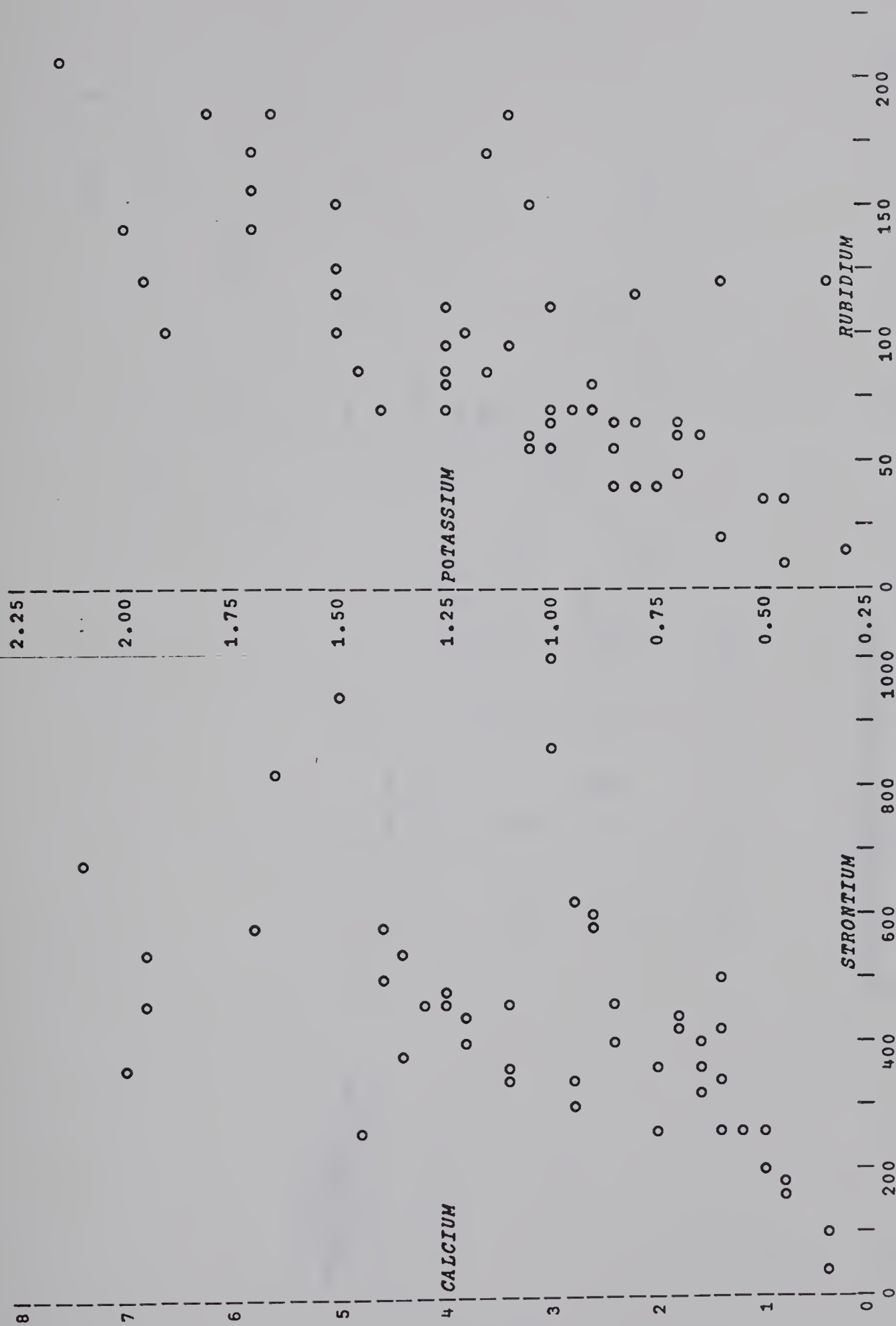


FIGURE 3.10. Ca - Sr AND K - Rb VARIATION DIAGRAMS

NOTE: Units of Rb and K are expressed in ppm and Wt % x 100 respectively.

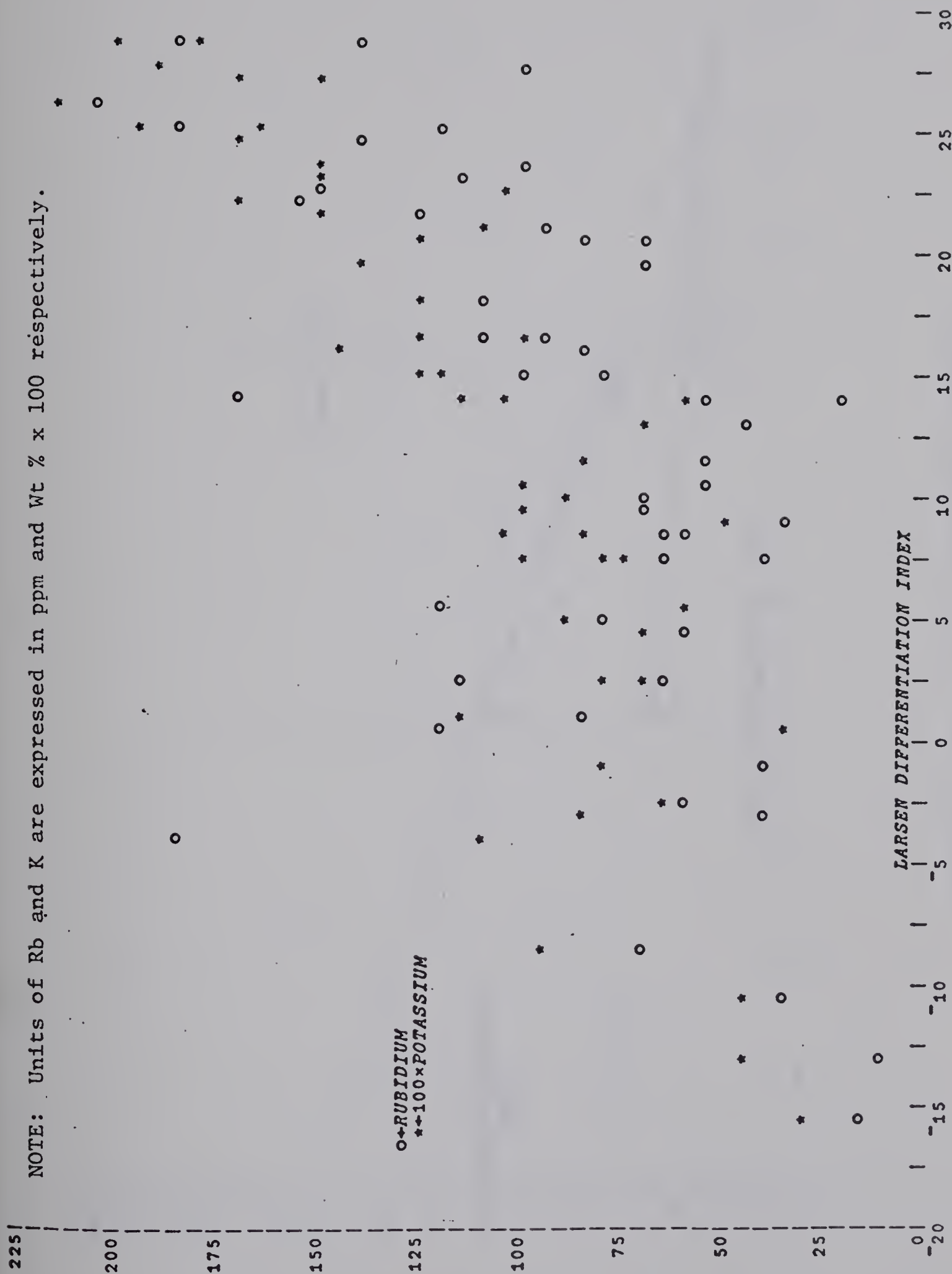


FIGURE 3.11. RUBIDIUM AND POTASSIUM TIMES 100 VARIATION DIAGRAM

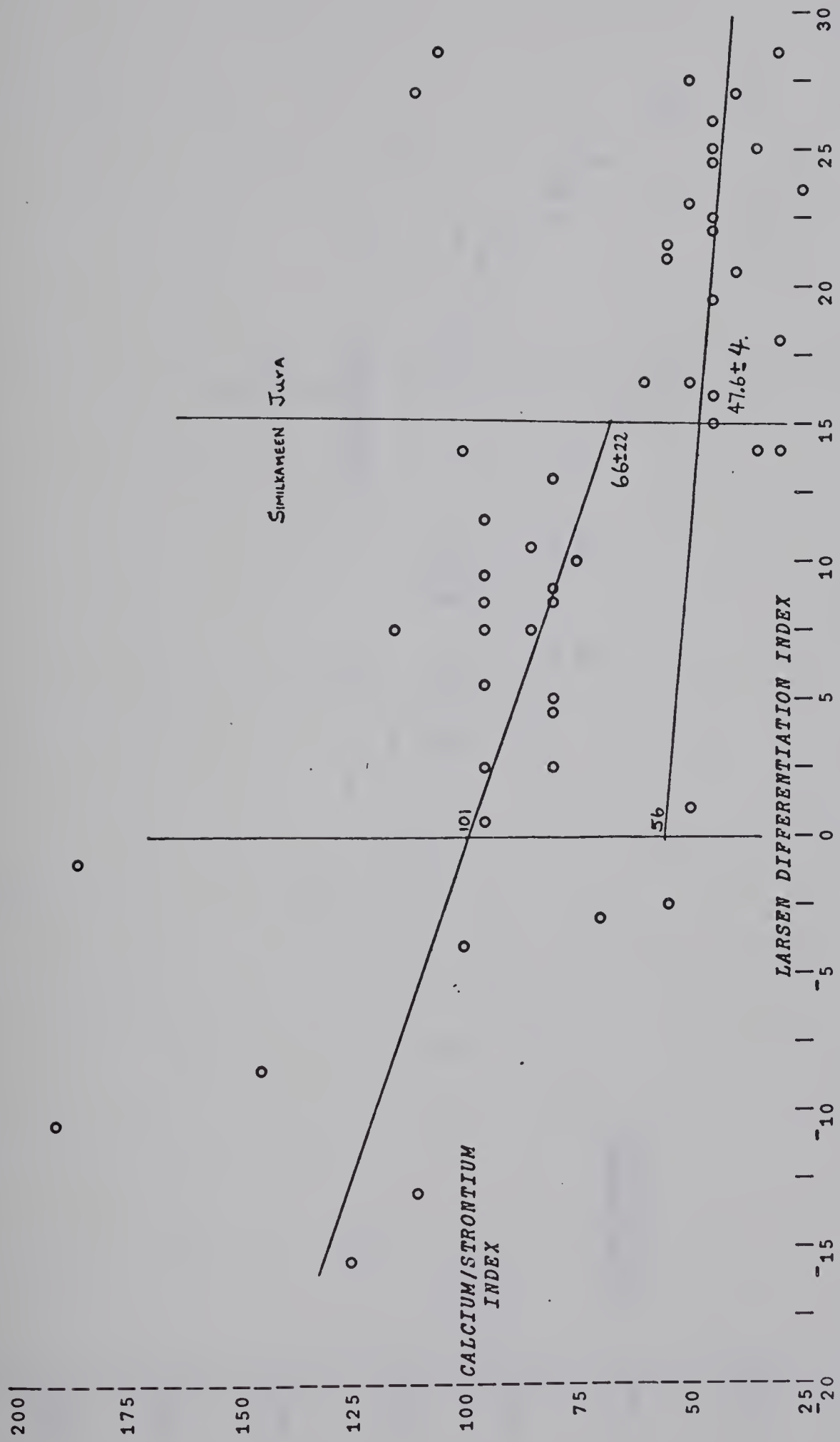


FIGURE 3.12. Ca/Sr VARIATION DIAGRAM

NOTE: Units of Sr and Ca are expressed in ppm and Wt % x 100 respectively.

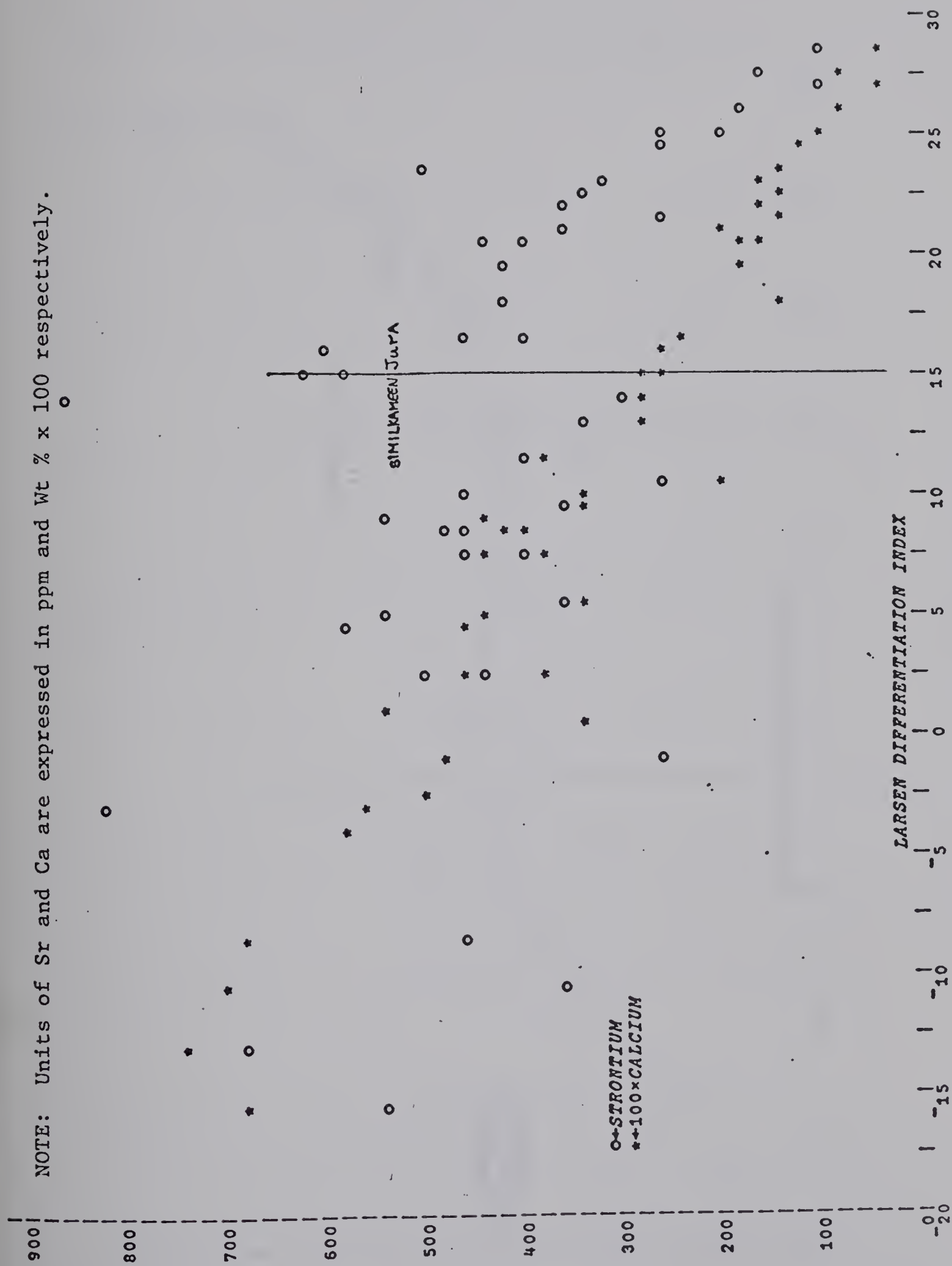


FIGURE 3.13. STRONTIUM AND CALCIUM TIMES 100 VARIATION DIAGRAM

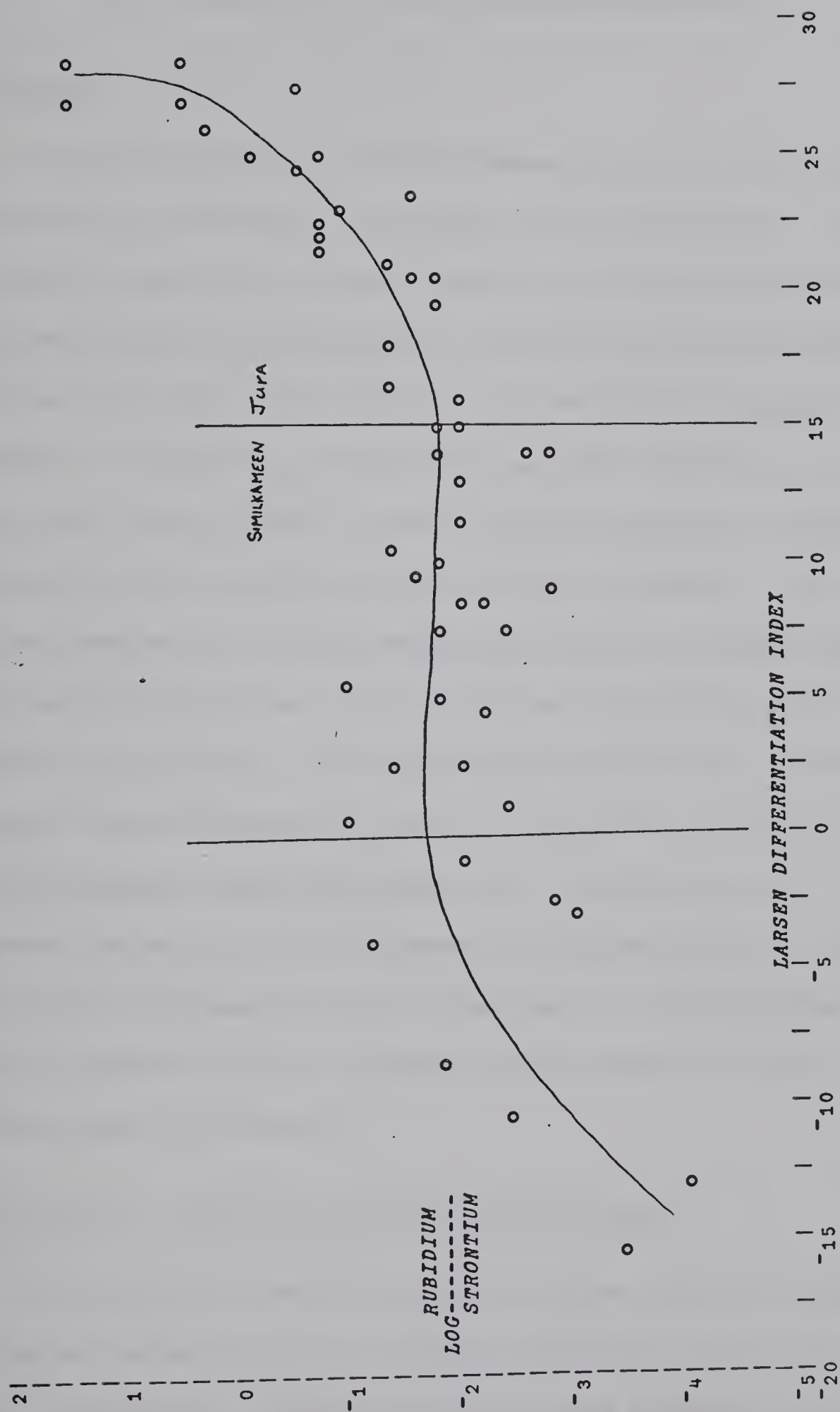


FIGURE 3.14. Rb/Sr VARIATION DIAGRAM

CHAPTER FOUR

THE PETROGENESIS OF THE SIMILKAMEEN BATHOLITH

Introduction

The petrogenesis of the Similkameen batholith is clearly indicated by its structure, petrography and petrochemistry. Field observations suggest that it was formed by a series of temporally and compositionally distinct magmatic episodes which were closely related to each other. The temporal and compositional magmatic succession is intimately related to the spatial succession in that the earliest rocks are basic and were intruded marginally whereas the youngest rocks are acid and were intruded centrally. The compositional succession is in fact a reflection of the lithologic sequence which consists of diorites, quartz diorites, granodiorites and adamellites respectively. The mineralogical abundances of each petrologic unit are listed in Table 4.1. The author therefore postulates that the most logical hypothesis for the formation of the Similkameen batholith is by the magmatic differentiation of a basic magma through a process of crystal fractionation. The question then arises as to whether the petrographic and petrochemical facts corroborate such a hypothesis.

The Petrogenetic Significance of Major Oxide Trends

The notion that major oxide distribution trends displayed in Harker and Larsen variation diagrams illustrate 'liquid lines of descent' is fallacious. The attributes of such distributions are due in part to the arithmetic restrictions of percentage systems or

systems of constant sum (Chayes, 1960, 1961, 1962a, 1962b; Vistelius and Sarmanov, 1961) and the usage of dependent indices creating situations of artificial correlation. Consequently these distributions are not due to the sampling of a heterogeneous continuously varying magmatic population but are due rather to the artificial constraints imposed upon it by the method of their representation. This, however, does not detract from the fact that silica and the Larsen Differentiation Index which is defined as $(1/3 \text{ SiO}_2 + \text{K}_2\text{O} - \text{CaO} - \text{MgO} - \text{FeO})$ are differentiation indices which are capable of measuring the relative difference between bulk compositions formed through a process of differentiation.

The sample population of bulk compositions within the Similkameen batholith as displayed in Table 3.1 and 3.2 probably indicates that the target population is a continuum of compositions ranging from approximately LDI 2.1 to 26.9. The sample population is either a comagmatic suite or it is not. The latter alternative is rejected for the following reasons.

1. It would be a highly fortuitous case if a series of distinct magma batches were all injected into a spatially restricted region of the crust in such a manner as to produce a compositionally continuous assemblage.

2. The observed plutonic lithologies all belong to the family of Calc-alkaline rocks.

3. The plutonic lithologies have similar K/Rb indices.

4. There is a continuous mineralogical, major and minor element trend over the entire compositional range.

It is self evident that if the sampled population is con-

sanguineous then it must be further inferred that its compositional diversity must be attributed to some process of differentiation.

Major oxide trends suggest therefore that the Similkameen batholith was formed by the diversification of a basic parental magma.

The Petrogenetic Significance of Normative Trends

Normative trends are dependent on major oxide trends and consequently the observed decline of normative hornblende, biotite and anorthite and the concomitant increase of normative orthoclase and quartz in progressively evolved bulk compositions is due to the progressive decline of MgO, FeO, and CaO in accordance with Bowen's reaction series. It is evident therefore that a magma must of necessity become more acidic by the progressive removal of hornblende, biotite and anorthite as noted in the previous chapter. Tables 3.1, 3.2, 3.4 and 4.1 suggest that a process of hornblende, biotite and plagioclase fractionation occurred within the Similkameen batholith. The increasing compositional variance with increasing basicity observed in Tables 3.2 and 4.1 is interpreted as resulting from compositions of an increasingly cumulative nature. Fractional crystallisation or indeed any form of crystallisation must result in the subsequent decline of entropy within a magma and the production of compositional differences within the magma. The consequent loss of homogeneity resulting from the compositional and spatial divergence of liquid and crystal populations results in a greater compositional variance within the magma. The compositional variance of the magma increases as the magma becomes increasingly cumulative providing that phenocrysts are sufficiently large and of significantly different composition. The dispersion of bulk compositions displayed in Figures 3A to 3D

are interpreted in a similar manner, implying that the bulk compositions of plutonic rocks represent the composition of two distinctly separate liquid and crystal populations whatever their relationship.

This interpretation is strongly corroborated by the following petrographic observations.

1. The earliest and most basic rocks display cumulus, hypidiomorphic granular textures typified by abundant, euhedral to subhedral, medium to coarse grained phenocrysts of plagioclase, hornblende and biotite with minor amounts of interstitial orthoclase and quartz.

2. Early formed calcic plagioclase phenocrysts display elaborate and complex zoning patterns suggesting a long and complicated reaction history with the parent magma.

3. Later, more acid rocks display allotriomorphic granular textures containing only minor amounts of highly chloritised mafics and very weakly zoned subhedral to anhedral sodic plagioclase suggesting crystallisation in situ.

The petrogenetic significance of the distribution of bulk compositions within the normative Granodiorite Tetrahedron is as follows.

1. As differentiation proceeded the anorthite component of the derivative liquid was continuously depleted in accordance with the continuous crystallisation of calcic plagioclase.

2. As the anorthite content of the crystallising plagioclase continuously decreased the derivative liquid became progressively enriched in quartz and orthoclase.

The Petrogenetic Significance of Minor Element Trends

The Rb trend displayed in Figure 3.9 suggests that there was a continuous enrichment of Rb in the liquid phase as differentiation proceeded. The change in the slope of the Pre - Jura and Post - Similkameen Rb trends may be interpreted as follows.

Both trends are unrelated and represent two separate magma batches having initially different rates of Rb enrichment. (Rate = 3.75 to 7.33 ppm Rb/LDI).

2. Both trends are related and the difference in slopes is the result of crystal fractionation. The former hypothesis is rejected because the K/Rb means of the Similkameen and Jura units are not significantly different at the 5% level.

The successive and continuous removal of non-rubidium bearing phases from the magma by fractional crystallisation must result in the enrichment of Rb within the liquid. The relatively large difference in the abundance of Rb between the Similkameen and Jura (Table 4.3) is attributed to a long period of hornblende and plagioclase fractionation resulting in a proportionately large enrichment of Rb. The Rb distribution coefficients for hornblende and plagioclase are .0448 and .0705 respectively (Philpotts and Schnetler, 1970) and are in accordance with such a scheme. The rapid increase of Rb in the Post - Similkameen trend is attributable to a continuous removal of hornblende, plagioclase and minor biotite by fractional crystallisation resulting in the progressive enrichment of Rb in successive derivative liquids. The multiple regression analysis displayed in Table 3.6 is in accordance with such a scheme. The orthoclase component to which Rb is strongly correlative probably

represents the proportion of K rich liquid present in the bulk composition.

The Sr trend displayed in Figure 3.9 can also be explained in terms of a fractional crystallisation scheme. Berlin and Henderson, 1968, have found that Sr in the liquid is selectively depleted by the crystallisation of plagioclase. The dispersion of Sr abundances within the Pre - Jura trend can be attributed to the variable proportion and composition of cumulus plagioclase. The discontinuity of the Sr trend at LDI = 15 suggests that Sr is enriched in the Jura relative to the Similkameen although the difference between them is not significant at the 5% level. This is in fact confirmed in figures 3.12 and 3.13 and Table 3.4 which indicate that Sr has been enriched relative to Ca. The fractional crystallisation of hornblende and biotite is capable of enriching the derivative liquid in Sr where their distribution coefficients are .188 and .120 respectively. (Philpotts and Schnetler, 1970) The rapid, uniform decrease of Sr within the Post - Similkameen trend can also be attributed to the crystallisation and successive removal of plagioclase and alkali feldspar from the derivative liquid; their respective distribution coefficients as given by Philpotts and Schnetler are 1.31 and 4.0. The multiple regression analysis listed in Table 3.6 is in accordance with the proposed scheme. Furthermore, Tables 4.2 and 4.3 indicate that the mean differences of Rb and Sr abundances among all petrologic units are easily significant at the 0.5% level but that the relative mean difference in abundance between two temporally successive petrologic units is only occasionally significant at the 5% level.

TABLE 4.1
Means and Standard Deviations of Modal Minerals of Rocks from the Similkameen Batholith

PETROLOGIC UNITS	K			SD			S			J			M			E			V		
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN
QUARTZ	8.6	3.4	7.4	6.0	26.4	6.9	26.9	5.6	28.0	5.4	30.8	4.0	28.0	5.4	30.8	4.0	28.0	5.4	28.0	5.4	28.0
K-FELDSPAR	4.0	2.2	3.5	3.1	11.4	5.7	14.4	6.0	24.0	7.7	32.9	6.1	24.0	7.7	32.9	6.1	15.8	10.4	15.8	10.4	15.8
PLAGIOCLASE	59	9.7	57.1	10.5	50.5	9.4	49.0	8.2	43.0	8.8	33.6	6.7	43.0	8.8	33.6	6.7	49.8	9.4	49.8	9.4	49.8
BIOTITE	6.4	8.5	6.5	7.7	5.0	4.5	5.3	3.8	4.8	3.5	2.4	1.6	4.8	3.5	2.4	1.6	4.9	2.3	4.9	2.3	4.9
HORNBLLENDE	21.0	14.9	25.4	13.8	6.7	5.4	4.4	3.8	0.2	0.7	0.3	0.9	0.2	0.7	0.3	0.9	1.5	2.4	1.5	2.4	1.5

TABLE 4.2

One - Way Analysis of Variance of Strontium Distributions

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SQUARE	F - VALUE				
AMONG UNITS	8	1128855	141106	4.538				
WITHIN UNITS	41	1274878	31094					
TOTAL	49	2403730						
PETROLOGIC UNITS	SD	I	S	J	XJ	M	E	V
MEANS	432	643	511	487	612	229	147	426
DIFFERENCE OF MEANS	K-SD 211	K-I 180	S-I 48	S-J 24	XJ-J 125	J-M 258	M-E 82	V-E 279
LEAST SIGNIFICANT DIFFERENCE	238	238	210	184	230	198	208	225
SIGNIFICANCE	NS	NS	NS	NS	NS	S	NS	S

NOTE: Least significant difference computed at 5% level.

TABLE 4.3

One - Way Analysis of Variance of Rubidium Distributions

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SQUARE	F - VALUE					
AMONG UNITS	8	61262	7657	8.103					
WITHIN UNITS	40	37801	945						
TOTAL	48	99063							
PETROLOGIC UNITS	SD	K	I	S	J	XJ	M	E	V
MEANS	60	52	71	70	101	127	152	149	85
DIFFERENCE OF MEANS	SD-K 7.6	I-K 19	I-S 1	J-S 31	XJ-J 26	M-J 50	M-E 3	E-V 63.8	
LEAST SIGNIFICANT DIFFERENCE	41	41	37	32	40	34	36	39	
SIGNIFICANCE	NS	NS	NS	NS	NS	S	NS	S	

NOTE: Least significant difference computed at 5% level.

TABLE 4.4

One - Way Analysis of Variance of Ca/Sr Distributions

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SQUARE	F - VALUE					
AMONG UNITS	8	33635	4204	9.182					
WITHIN UNITS	39	17858	457						
TOTAL	47	51494							
PETROLOGIC UNITS	SD	K	I	S	J	M	E	V	
MEANS	139	75	75	85	45	76	44	65	41
DIFFERENCE OF MEANS	SD-K	I-K	S-I	S-J	XJ-J	J-M	E-M	E-V	
	64	0.4	10	35	31	1	21	24	
LEAST SIGNIFICANT DIFFERENCE	29	29	26	23	31	24	27	28	
SIGNIFICANCE	S	NS	NS	S	S	NS	NS	NS	

NOTE: Least significant difference computed at 5% level.

The Rb/Sr abundances displayed in Figure 3.14 essentially indicates the progression of successively evolved bulk compositions. The trend is essentially symmetrical about cumulative and derivative compositions. Table 4.5 indicates the magnitude and extent of the differentiation process for specific differentiation indices. The magnitude of differentiation is measured by the value of the ratio of the differentiation indices for the earliest and latest petrologic units.

TABLE 4.5

$\text{Rb}(\text{Empress})/\text{Rb}(\text{Kirton})$	$= 2.86$
$\text{Sr}(\text{Empress})/\text{Sr}(\text{Kirton})$	$= 0.23$
$\text{Zn}(\text{Empress})/\text{Zn}(\text{Kirton})$	$= 0.30$
$\text{Cu}(\text{Empress})/\text{Cu}(\text{Kirton})$	$= 0.33$
$\text{Rb}/\text{Sr}(\text{Empress})/\text{Rb}/\text{Sr}(\text{Kirton})$	$= 12.45$
$\text{Ca}/\text{Sr}(\text{Empress})/\text{Ca}/\text{Sr}(\text{Kirton})$	$= 0.87$
$\text{K}/\text{Rb}(\text{Empress})/\text{K}/\text{Rb}(\text{Kirton})$	$= 0.83$

Some Interrelationships within the Similkameen Batholith

It is difficult to propose a unified hypothesis which can simultaneously explain the temporal, structural, and compositional interrelationships of the petrologic succession observed within the Similkameen batholith. The following inferences are postulated.

1. The Summerland diorite is probably a hornblende rich cumulate of the Similkameen quartz diorite.
2. The Isintok diorite is slightly more basic but not significantly different compositionally from the Similkameen quartz diorite.

TABLE 4.6

Comparison of Minor Element Means between the Jura and its Xenoliths

PARAMETER	JURA MEAN	XENOLITH MEAN	MEAN DIFFERENCE	LSD (.05)	SIGNIFICANCE
Rb	101.6	127.5	25.9	40.1	NS
Sr	487	612	125	230	NS
Rb/Sr	.208	.208	--	--	NS
K/Rb	128.6	77.6	51	53.4	NS
Ca/Sr	45.2	76.6	31.4	31.1	S
K	3.1	3.1	--	--	NS

3. The Similkameen quartz diorite is predominantly cumulative and the Jura, McNulty and Empress are predominantly derivative.

4. The Valhalla and Coryell intrusives are not compositionally and temporally related to the Similkameen intrusives.

5. The Similkameen, Summerland and Kirton petrologic units constitute the marginal and abyssal portions of the batholith whereas the Jura, McNulty and Empress petrologic units constitute the central and hypabyssal portions of the batholith.

The Crystallisation History of the Similkameen Batholith

The following crystallisation sequence is postulated to account for the development of the Pre - Jura and Post - Similkameen trends. A basic, hydrous, parental magma probably began its crystallisation history by precipitating apatite, magnetite, sphene and hornblende followed soon afterwards by calcic plagioclase and biotite. As these crystals began to form the magma began to fractionate through a process of crystal settling forming a predominantly cumulative magma and a derivative magma having a bulk composition which continuously approached the residua system as fractional crystallisation proceeded. This can be depicted by describing the crystallisation sequence within the Granodiorite Tetrahedron. The parental magma has a bulk composition lying within the primary phase field of plagioclase. As plagioclase crystallises it depletes the anorthite content of the liquid and drives the liquid composition away from the bulk composition towards the residua system. There are now two bulk compositions. One representing a liquid in equilibrium with cumulus plagioclase and another liquid having a

composition richer in soda, potash and silica but depleted in lime. As the cumulative rich magma continues to crystallise the liquid composition is driven toward the quartz - plagioclase divariant surface. When the liquid reaches this surface it begins to crystallise quartz as well as plagioclase. The interstitial liquid then becomes depleted in silica and moves along the quartz - plagioclase surface towards the three - phase univariant line. If the cumulative magma continues to fractionate it will crystallise quartz and plagioclase until it reaches the cotectic line whereupon it will begin to crystallise alkali feldspar as well as quartz and plagioclase until the liquid is depleted. If the cumulative magma ceases to fractionate it will undergo equilibrium crystallisation and crystallise quartz and plagioclase as long as there is liquid remaining. Generally, the Similkameen quartz diorite contains very little interstitial orthoclase suggesting that the liquid was depleted just as it reached the cotectic line. The large variance of modal orthoclase within the Similkameen quartz diorite further suggests that the degree of fractionation was variable in different parts of the magma chamber.

The derivative magma, however, has a different crystallisation sequence. It is no longer in equilibrium with cumulative plagioclase and as it cools it begins to crystallise a more sodic plagioclase which drives the liquid composition away from the new bulk composition towards the alkali feldspar - plagioclase divariant surface. This magma may also begin to fractionate by the removal of newly crystallised plagioclase. In any case, when the liquid intersects the two - feldspar surface it begins to crystallise alkali

feldspar. The liquid now becomes depleted in lime, soda and potash and becomes enriched in silica. The liquid is consequently driven along the two - feldspar surface to the cotectic line. When the liquid reaches this surface it will begin to crystallise quartz as well as alkali feldspar and plagioclase until it is depleted. The increase in modal alkali feldspar and quartz as well as the decrease of modal plagioclase in the Post - Similkameen series suggests that a progressively longer period of crystallisation along the three phase univariant line has occurred. The notion that microcline megacrysts of intermediate porphyries are earlier crystallates than groundmass microclines has been proposed by Kerrick, 1969, for the Cathedral Peak quartz monzonite. The Jura microcline megacrysts may in fact be the first alkali feldspar to form as the liquid crystallises along the two feldspar surface and their perthitic texture is probably due to subsequent cooling under subsolvus conditions. That they are indeed magmatic crystallisation products is indicated by their finely textured concentric zoning and concentrically aligned mafic inclusions. The progressive depletion of soda and the concomitant increase of potash observed in the Post - Similkameen trend of Figure 3.4 suggests that albitic plagioclase was being fractionated.

From the data of James and Hamilton, 1969, alkali feldspar can only begin to crystallise from liquids having compositions of less than 10% anorthite at a water vapour pressure of one kilobar. Therefore the proportion of alkali feldspar-producing liquid is limited by the anorthite content of the bulk composition. From Figure 3B it is evident that the bulk compositions of the McNulty

Creek and Empress units contain a substantial proportion of alkali feldspar-producing liquid but that bulk compositions of progressively increasing anorthite content must have contained very little liquid capable of crystallising alkali feldspar.

The Petrogenesis of Jura Xenoliths

Table 4.6 indicates the great similarity in the minor element distributions between xenoliths and their host rock. The author therefore proposes that Jura xenoliths are mafic cumulates resulting from the late crystal fractionation of hornblende, biotite, calcic plagioclase, magnetite and sphene from the Jura magma. The occurrence of microcline megacrysts within some xenoliths probably indicates that alkali feldspar has settled out along with other mafic constituents. The unique dispersion of the xenoliths relative to the main trend as indicated by figures 3A and 3B testifies to their cumulative nature. Table 4.6 also indicates that the mean Ca/Sr index is significantly different between the xenoliths and their host. The relative depletion of Ca with respect to Sr within the Jura and the relative enrichment of Ca with respect to Sr within the xenoliths is in accordance with a crystal fractionation scheme. The ubiquitous distribution and variable density of these xenoliths throughout the Jura may be attributed to the forceful injection of Jura magma from depth into the hypabyssal portions of the magma chamber resulting in the fragmentation and subsequent transportation of cumulative mafic residua.

CHAPTER FIVE

CONCLUSION

Experimental melting relationships within a series of calc - alkaline rocks have been determined by Piwinskii, 1968a, 1968b, Piwinskii and Wyllie 1968, 1970, and Gibbon and Wyllie, 1969. Their experimental observations are of considerable petrogenetic significance and are relevant to the genesis of the Similkameen batholith. Piwinskii, Wyllie and Gibbon have established the experimental basis for the hypothesis proposed here.

The long temperature interval between the initial crystallisation of magnetite, hornblende and calcic plagioclase and the final crystallisation of quartz and feldspar cited in Piwinskii and Wyllie, 1968, is of particular significance. It was observed that the temperature interval between the initial and final crystallisation of a plutonic calc - alkaline rock series increases with the partial vapour pressure of water and the basicity of bulk compositions. This implies that early phenocrysts of hornblende and calcic plagioclase would be in contact with a slowly cooling magma for a considerable period of time. This notion is especially applicable to batholiths where cooling rates are presumably quite slow. It is probable, therefore, that dense early formed phenocrysts would have sufficient time to sink through a predominantly liquid magma by a process of crystal settling and that the degree of crystal settling is in part controlled by the rate of cooling of the magma. The rim and core composition of plagioclase phenocrysts cited by Piwinskii, 1968a, indicates that they have undergone a relatively prolonged

reaction history with the magma. Piwinskii, 1968¹, and Piwinskii and Wyllie, 1970, concluded that at a partial water vapour pressure of two kilobars temperatures in excess of 950°C are required to produce granodioritic and quartz dioritic liquids and that temperatures of at least 730°C and 780°C are required to produce liquids of granitic and quartz monzonitic composition. Piwinskii and Wyllie, 1970, also conclude that the partial pressure of water within a closed magma-water system will decrease continuously as the abundance and temperature of a partial melt increases. Fairbairn, et al., 1964, have determined an average $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of .7071 for the Similkameen quartz diorite. These observations impose severe limitations on the possible source and origin of batholithic magmas.

Several hypotheses have been proposed concerning the origin of batholithic rocks. Among these is the notion that batholithic rocks were formed by the partial melting at depth of eugeosynclinal rocks. Although the Similkameen batholith was intruded into a 'typical' eugeosynclinal assemblage the author rejects the notion that it was formed through a process of differential anatexis of crustal materials.

The observed petrologic succession as well as normative major and minor element trends would be difficult to explain unless it is assumed that partial melting was areally and compositionally extensive, resulting in a melt of at least granodioritic composition. This is unlikely as it would require a partial vapour pressure of water equal to two kilobars and a temperature in excess of 950°C to produce a liquid of such a composition. Partial melts consisting of quartz monzonitic liquids and basic residua would require

temperatures of 980°C at the same water vapour pressure, but if this partial melt was of granodioritic composition then it would consist of approximately 51% liquid at 800°C at the stated water vapour pressure; whereas a quartz dioritic partial melt would consist of only 29% liquid and 71% solid residua. (Piwinskii, 1968b)

Rubidium and Sr abundances in batholithic rocks do not appear to be compatible with partial melts derived from average sediments. Strontium is typically enriched in batholithic rocks whereas Rb abundances are generally lower than those of average sediments. As Piwinskii and Wyllie, 1970, have noted, partial melting under optimum crustal conditions can only produce intermediate magmas consisting of 'crystal mushes' involving water undersaturated granitic liquids. The final objection to the generation of batholithic magmas from eugeosynclinal assemblages by differential anatexis are the $\text{Sr}^{87}/\text{Sr}^{86}$ values cited by Fairbairn et al., 1964, and Hurley et al., 1965. In summary, therefore, the conditions required for the generation, transportation and emplacement of partial melts derived from crustal assemblages impose extreme demands on the capabilities of a crustal environment.

The areal and compositional distributions of batholithic rocks strongly suggest that batholiths have a subcrustal origin. The association of batholiths with orogenic zones implies that they are probably the product of an orogenic environment involving major crustal and subcrustal transformations. It is not unreasonable to suppose that the extensive volcanism and plutonism of orogenic areas are closely interrelated and have a common subcrustal affiliation. This is quite evident in the Similkameen batholith where

periods of basic volcanism precede and post date the time of plutonism suggesting that the mantle was continuously active throughout the entire igneous orogenic episode. The author, postulates that large regions of the upper mantle were involved in the generation of batholithic magmas and that anomalous temperature gradients and crustal instability of orogenic regions provided favourable conditions for the generation, transportation and emplacement of batholithic magmas. The author further postulates that primary batholithic magmas generated within the mantle are basic in composition and that through a period of relatively slow emplacement and thermal consolidation they undergo extensive differentiation through a process of crystal fractionation resulting in derivative magmas quite unlike the original parent magma.

The K/Rb abundances observed within the Similkameen batholith indicate a considerable enrichment of Rb relative to K. If the Similkameen batholith was derived from the upper mantle then a considerable amount of liquid fractionation must have occurred. An examination of K/Rb distribution coefficients given by Philpotts and Schnetler, 1970, suggests that the K/Rb index of a liquid can be greatly reduced by the fractional crystallisation of plagioclase, hornblende and biotite and that Sr can be further enriched by the fractional crystallisation of pyroxene, hornblende and biotite. The author maintains that the Similkameen batholith is not unlike other North American Mesozoic batholiths in terms of its structure, petrography, petrochemistry and petrogenesis and that generally it represents a 'normal' batholith but not without its own distinct character.

REFERENCES

- BARTH, T., 1959, Principles of classification and norm calculations of metamorphic rocks: Jour. Geol., v. 67, p. 135-152.
- BERLIN, R., and HENDERSON, C., 1968, A reinterpretation of Sr and Ca fractionation trends in plagioclases from basic rocks: Earth Plant. Sci. Lett., v. 4, p. 79-83.
- BOSTOCK, H.H., 1966, Feldspar and quartz phenocrysts in the Shingle Creek Porphyry, British Columbia: Geol. Survey Canada Bull., v. 126.
- BOSTOCK, H.S., 1930, Geology and ore deposits of nickel plate mountain, Hedley, B.C.: Geol. Surv. Canada, Sum. Rept. 1929, pt. A.
- CAMSELL, C., 1907, Preliminary report on a part of the Similkameen district, British Columbia: Geol. Surv. Canada, Special Report 986.
- CARR, J., 1968, The geology of the Brenda Lake area: Minister of Mines, B.C., Ann. Repts., p. 183-211.
- CHAYES, F., 1960, On correlation between variables of constant sum: J. Geophys. Res., v. 65, p. 4185-4193.
- _____, 1961, Numerical petrography: Carnegie Inst. Wash. Yr. Book, v. 60, p. 158-165.
- _____, 1962a, Numerical correlation and petrographic variation: Jour. Geol., v. 70, p. 440-452.
- _____, 1962b, Variance relations in some published Harker diagrams: Carnegie Inst. Wash Yr. Book, v. 61, p. 118-119.
- DALY, R., 1912, Geology of the North American Cordillera at the forty-ninth parallel: Geol. Surv. Canada, Mem. 38, p. 443-506.
- DAWSON, G., 1877, Report on explorations in British Columbia: Geol. Surv. Canada, Report of Prog. 1875-1876, p. 233-265.
- DODGE, F., PAPIKE, J., and MAYS, R., 1968, Hornblende from granitic rocks of the Central Sierra Nevada batholith: Jour. Petrol., v. 9, p. 378-410.
- DODGE, F., SMITH, X., and MAYS, R., 1969, Biotite from granitic rocks of the Central Sierra Nevada batholith: Jour. Petrol., v. 10, p. 250-271.
- FAIRBAIRN, H., HURLEY, P., and PINSON, W., 1964, Initial $\text{Sr}^{87}/\text{Sr}^{86}$ and possible sources of granitic rocks in Southern British Columbia: Jour. Geophys. Res., v. 69, p. 4889-4893.

- GIBBON, D., and WYLLIE, P., 1969, Experimental studies of igneous rock series: the Farrington Complex, Northern Carolina and the Star Mountain Rhyolite, Texas: *Jour. Geol.*, v. 77, p. 221-239.
- HURLEY, P., BATEMAN, P., FAIRBAIRN, H., and PINSON, W., 1965, Investigation of initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios in the Sierra Nevada plutonic province: *Geol. Soc. America Bull.*, v. 76, p. 165-174.
- JAMES, R., and HAMILTON, D., 1969, Phase relations in the system $\text{NaAlSi}_3\text{O}_8 - \text{KAlSi}_3\text{O}_8 - \text{CaAl}_2\text{Si}_2\text{O}_8 - \text{SiO}_2$ at 1 kilobar water vapour pressure: *Contr. Mineral. and Petrol.*, v. 21, p. 111-141.
- KERRICK, D., 1969, K-feldspar megacrysts from a porphyritic quartz monzonite Central Sierra Nevada, California: *Amer. Min.*, v. 54, p. 839-848.
- KRUMBEIN, W., and Graybill, F., 1965, An introduction to statistical modals in geology: McGraw-Hill Book Co. Inc.
- LEECH, G., LOWDEN, J., STOCKWELL, C., and WANLESS, R., 1963, Age determinations and geological studies: *Geol. Survey Canada paper* 63-17.
- MAXWELL, J., DAWSON, K., TOMILSON, M., POCOCK, D., and TETREAULT, D., 1965, Chemical Analysis of Canadian rocks, minerals and ores: *Geol. Surv. Canada Bull.* 115.
- NORRISH, K., and HUTTON, J., 1969, An accurate X-ray spectrographic method for the analysis of a wide range of geological samples: *Geochim. Cosmochim. Acta*, v. 33, p. 431-453.
- PARSLOW, G., 1969, Mesonorms of granitic rock analyses: *Min. Mag.*, v. 37, p. 262-269.
- PHILPOTTS, J., and SCHNETLER, C., 1970, Phenocryst-matrix partition coefficients for K, Rb, Sr and Ba with applications to anorthosite and basalt genesis: *Geochim. Cosmochim. Acta*, v. 34, p. 307-322.
- PIWINSKII, A., 1968a, Studies of batholithic feldspars: Sierra Nevada, California: *Contr. Mineral. and Petrol.*, v. 17, p. 204-223.
- _____, 1968b, Experimental studies of igneous rock series: Central Sierra Nevada batholith, California: *Jour. Geol.*, v. 76, p. 548-570.
- PIWINSKII, A., and WYLLIE, P., 1968, Experimental studies of igneous rock series: a zoned pluton in the Wallowa batholith, Oregon: *Jour. Geol.*, v. 76, p. 205-234.
- _____, 1970, Experimental studies of igneous rock series: felsic body suite from the Needle Point pluton, Wallowa batholith, Oregon: *Jour. Geol.*, v. 78, p. 52-76.

- RICE, H., 1960, Geology and mineral deposits of the Princeton map area, British Columbia: Geol. Survey Canada Mem. 243.
- STEEL, R., and TORRIE, J., 1960, Principles and procedures of statistics: McGraw-Hill Book Co. Inc.
- VISTELIUS, A., and SARMANOV, O., 1961, On the correlation between percentage values: major component correlation in ferro-magnesian micas: Jour. Geol., v. 69, p. 145-153.
- WANLESS, R., STEVENS, R., LACHANCE, G., and EDMONDS, C., 1967, Age determinations and geological studies: Geol. Survey Canada paper 66-67.
- WHITE, H., ERICKSON, G., NORTHCOTE, K., KIROM, G., and HARAKAL, J., 1967, Isotopic dating of the Guichon Batholith, B.C.: canadian Jour. Earth Sci., v. 4, p. 677-690.

APPENDIX A

X-RAY SPECTROGRAPHIC ANALYSIS

Introduction

X-ray spectrographic analyses were employed on selected rock samples using a modified version of the fusion method outlined by Norrish and Hutton, 1968. The most obvious advantages of the fusion method are as follows.

1. By fusing a constant weight of sample and flux it is possible to produce and reproduce a homogeneous resilient glass of uniform density.
2. It is possible to normalize matrix effects through a process of sample dilution with the addition of a heavy absorber resulting in a glass which displays a constant, linear relationship between fluorescent intensity and concentration.

Sample Preparation

Samples were prepared as suggested by Norrish and Hutton with the exception that .295 grams of sample were mixed with 1.6 grams of flux in order to produce a thicker and stronger disk upon casting.

Drift Corrections

Drift corrections were found to be necessary due to the instability of the x-ray spectrometer with time. A short-term correction was made by bracketing every three samples between a standard and then distributing the observed drift by appropriate increments to each sample. Long-term drift corrections were made by

applying to each sample a correction factor based on the difference of the count rate of the standard at 'graph time' and the middle of each cycle.

Discussion of Results

A linear regression analysis of each calibration plot is listed in Table 5.1 from which it is evident the resulting linear regression equations have a high degree of predictability. The error limits of the slope and the relative error were computed at the 0.1% level and with the exception of titania the observed relative errors are within the calculated limits. The calculated errors of the Rb and Sr regression equations are well within the uncertainty of the standard values. Since H_2O^+ , H_2O^- , P_2O_5 , MnO and CO_2 were not included in the analysis; totals of approximately 97% or better are considered to be reasonable analyses and amply adequate for the purpose of this treatise. Five analyses of the 56 rock analyses were rejected on the basis of this criterion.

Possible Sources of Error

Total analytical error results from errors in sample preparation, sample fusion and instrumental variability. The following list indicates such possible sources of error:

1. Sample errors

- (a) inhomogeneity within the sample
- (b) weighing inaccuracies
- (c) loss of volatiles upon fusion

2. Fusion errors

- (a) inhomogeneity and microsegregation within the glass
- (b) surface irregularities and carbon contamination upon moulding

- (c) variable count rates due to varying temperatures of fusion (Norrish, 1969, p. 435)
- (d) matrix effects

3. Instrumental errors

- (a) sample positioning
- (b) pulse height drift
- (c) voltage stabiliser drift.

TABLE 5.1
X.R.F. Calibration Statistics

OXIDE	SiO ₂	Al ₂ O ₃	MgO	Fe ₂ O ₃	TiO ₂	CaO	Rb	Sr
COUNTS/SEC/WT %	12.5 $\pm$ 0.22	11.01 $\pm$ 0.99	2.69 $\pm$.09	382.12 $\pm$ 11.80	315.1 $\pm$ 15	63.26 $\pm$ 1.90	0.73 $\pm$ 0.19	0.88 $\pm$ 0.08
BACKGROUND	-12.48	-14.16	1.73	89.16	-2.37	23.90	31.76	-4.62
STANDARD ERROR OF ESTIMATE	7.440	9.000	0.164	35.800	5.900	6.600	11.380	11.960
CORRELATION COEFFICIENT	0.999	0.970	1.000	1.000	1.000	1.000	0.987	0.997
DEGREES OF FREEDOM	9	9	7	8	7	8	7	7
T-VALUE	54.05	10.60	141.00	123.40	93.68	129.00	14.05	32.60
THEORETICAL RELATIVE ERROR	$\pm$ 1.7%	$\pm$ 9.0%	$\pm$ 3.3%	$\pm$ 3.1%	$\pm$ 4.7%	$\pm$ 3.0%	$\pm$ 13.1%	$\pm$ 4.9%
OBSERVED RELATIVE ERROR	$\pm$ 1.5%	$\pm$ 1.4%	--	$\pm$ 2.6%	$\pm$ 6.8%	$\pm$ 3.0%	--	--

NOTE: Error limits were calculated at the 0.1% level.

APPENDIX B

CHEMICAL ANALYSIS

Copper, molybdenum, lead, zinc, and silver analyses were determined in the geochemical laboratory of Anaconda American Brass by laboratory technicians using atomic absorption methods. The following procedure was employed. A one gram rock sample was digested in a test tube containing ten mls of concentrated HCl and three mls of concentrated HNO_3 until dryness. The residue was then taken up to twenty-five mls with two mls of HCl and distilled water. The solution was gently heated and left overnight to settle. The supernatant was then run for analysis. Sodium and potassium were determined by flame photometer by the author and he believes that the analyses are accurate to a tenth of a percent absolute. A simple $\text{HF} - \text{H}_2\text{SO}_4$ acid leach was employed using a MgCl buffer.

APPENDIX C

GRANODIORITE NORM

The Granodiorite Norm is designed to calculate the normative constituents of granodioritic rocks in terms of common modal minerals such as hornblende, biotite, plagioclase, alkali feldspar, magnetite and sphene. Barth, 1959, and Parslow, 1969, have discussed the inadequacy of the CIPW norm applied to the projection of 'granitic' rocks into the system Ab - Qtz - Or. The primary objection to the CIPW norm is that it allocates all the K of silica saturated rocks to K - feldspar when in actual fact significant amounts of K are bound up in biotite. Therefore normative projections of 'granitic' rocks computed according to the CIPW norm differ significantly from the synthetic system Ab - Qtz - Or, especially when appreciable amounts of modal biotite are present. Barth therefore formulated a new norm which includes biotite in the normative calculation thereby approaching the natural system more closely. A similar inadequacy of the CIPW norm applies to granodioritic rocks which may be described by the system Ab - Qtz - Or - An - H₂O. If a norm purports to approximate the elemental distribution in minerals of natural systems then the CIPW norm does not apply adequately to granodioritic rocks because it does not account for the presence of Ca, Na, K, Mg, Fe, Ti and Si in such common modal minerals as hornblende and biotite. If this is the case then it must of necessity over-allocate these elements to other minerals and thereby deviate from natural and synthetic granodiorite systems. From a petrogenetic standpoint it is important that a normative calculation approximate the natural

system as closely as possible and consequently the Granodiorite Norm was constructed in the following manner.

The average composition of coexisting biotites and hornblendes from the Sierra Nevada batholith was determined from the data of Dodge, et al., 1968, 1969, and normative minerals were computed on the following assumptions.

1. The composition of Sierra Nevadan biotites and hornblendes are typical of a batholithic environment and are a first approximation to hornblendes and biotites within the Similkameen batholith.

2. The absolute amounts of hornblende and biotite are determined by the amount of MgO present within the rock.

3. The relative amounts of biotite and hornblende are determined by the partitioning of MgO between those minerals.

4. The proportions of MgO partitioned between those minerals are approximated by their relative modal abundance times the relative concentration coefficient of MgO in each phase. i.e. In Sierra Nevadan granodiorites on the average there is 1.0659 times more MgO in hornblende than in biotite.

5. On the basis of the average composition of coexisting biotite and hornblende, the average stoichiometric coefficients determine the absolute amounts of K, Ca, Na, Fe, Ti, Al, and Si which are allocated to those phases.

6. Having allocated appropriate elemental amounts to biotite, hornblende, magnetite and sphene, the remaining elemental constituents approximate the quartzo-feldspathic constituents of the rock.

A comparison of differences between the CIPW and Granodiorite

norms within the Ab - Qtz - Or and Ab - An - Or systems indicate the following.

1. In the system Ab - Qtz - Or there is a net vectorial displacement, as the amount of modal biotite increases, towards lower orthoclase compositions and away from the CIPW composition point by a magnitude specified by the amount of K in the rock minus the amount of K in biotite.

2. Similarly, that as the amount of modal hornblende increases there is a net vectorial displacement toward lower albite compositions away from the CIPW composition point by a magnitude specified by the amount of Na present in the rock minus the amount of Na in hornblende.

3. That in the system Ab - An - Or there is a net vectorial displacement as the amount of modal biotite increases toward lower orthoclase compositions along an albite composition line away from the CIPW composition point by a magnitude dependent on the amount of K in the rock minus the amount of K in biotite.

4. Similarly, as the amount of modal hornblende increases, there is a net vectorial displacement toward lower An compositions along an albite composition line away from the CIPW composition point by a magnitude specified by the amount of Ca in the rock minus the amount of Ca present in hornblende.

If the assumptions upon which the norm is based approximate the natural distribution of elements within a granodioritic rock then the accuracy of a normative calculation depends upon the accuracy of the concentrations of Si, Mg, Na, K, Ca and the relative amounts of modal biotite and hornblende present. Since the relative

amounts of biotite and hornblende were determined by visual estimation any error attendant on this observation is transferred to a specific normative phase according to the following equation.

$$NP = e - MgO \times H-B \times C$$

Where NP is the error in a specific normative phase, e is the amount of element in the rock which controls that phase, MgO is the amount of magnesium in the rock, H-B is the error in the relative difference of hornblende and biotite and C is a constant usually less than one.

APPENDIX D

FIELD METHODS

Reconnaissance field mapping and rock specimen sampling of the Similkameen batholith involved the use of vertical areal photographs on the scale of 1 inch to 1/4 mile and 1 inch to 1/2 mile as well as the use of topographic maps on the scale of 1 inch to 50,000 inches in conjunction with pace and compass and road-side traverses. These provided the basic information from which the sample location and geological maps (in pocket) were constructed. The geological map does not indicate topographic features in order to protect the exploration interests of Anaconda American Brass Ltd. The method and extent of rock specimen sampling was necessarily restricted by logistic and physiographic considerations and consequently the author has attempted to collect and record as many rock specimens covering the greatest area within the time and resources available to him. Each rock specimen which was collected was sawn into two parts, stained for alkali feldspar using the sodium cobaltinitrite technique and examined under a binocular microscope. The abundances of modal minerals were estimated visually and figures quoted in chapter two and Table 4.1 represent the averages and standard deviations of these visual estimates. In the process of mapping, 1056 specimens were collected from which 105 thin sections were made. Thin sections were also stained for alkali feldspar and An determinations were made optically using the Michel-Levy method.

APPENDIX E

STATISTICAL METHODS

The use of statistical methods within this treatise is an attempt to introduce a measure of scientific rigour into the evaluation of petrochemical data. To this effect inferences concerning petrochemical data are formulated within a calculus of probability statements rather than as intuitive declarations. Multiple and simple linear regression analysis and analysis of variance methods are used in the evaluation of relationships and inter-relationships between various petrochemical parameters. The reader is referred to Steele and Torrie, 1960, and Krumbein and Graybill, 1965, for a description of the statistical methods and terms employed within this treatise.

SILKAMEEN BATHOLITH ST

SAMPLE LOCATION MAP

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